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Food Habits of Spotted Sand Bass (*Paralabrax maculatofasciatus,* Serranidae) from Bahia De Los Angeles, Baja California

Lara A. Ferry[1]*, Stephen L. Clark[2], and Gregor M. Cailliet

Moss Landing Marine Laboratories, P.O. Box 450,
Moss Landing, California 95039 USA

Abstract.—In this study, we compare feeding habits of spotted sand bass, *Paralabrax maculatofasciatus,* between two sampling periods, fall 1992 and spring 1994, characterized by different local oceanographic and environmental conditions, at Bahia de Los Angeles, Baja California, Mexico. Fish, ophiuroids, and brachyuran crabs dominated sand bass diet in fall 1992, contrasted with mysids in 1994. Diet was more diverse in 1992 than in 1994, and higher in prey evenness and lower in index of specialization and prey dominance, indicating a few items had a large impact on the diet in 1994. Among size classes within each year sampled, the largest fish consumed the most mobile prey items. The spotted sand bass' ability to utilize such a wide variety of prey appears to be the key to its success in varying habitats.

Serranids (sea basses) are a diverse group with over 400 species worldwide (Thomson et al. 1987). The Gulf of California contains a particularly broad representation of basses, with 33 species from 11 genera (Thomson et al. 1987). Only 12 species from seven genera live off the coast of California (Miller and Lea 1972), nine of which range into the Gulf (Thomson et al. 1987).

One of these species is the spotted sand bass, *Paralabrax maculatofasciatus.* The spotted sand bass is distributed along the central and southern California coast to Cabo San Lucas and Mazatlan, and throughout the Gulf of California from the rocky intertidal to about 60 m. Although the species ranges over a wide geographic area, the populations in the Gulf and off southern California are geographically isolated by the Baja Peninsula and probably are distinct (genetically isolated) populations. Spotted sand bass are more abundant in the northern Gulf than the southern Gulf (Thomson et al. 1987), and Korsmeyer (1991) proposed that *Paralabrax* species in the northern Gulf have evolved to withstand high temperatures.

The spotted sand bass is a eurythermal species tolerating temperatures in excess of 32°C (Thomson et al. 1987). It survives periodic winterkills of fishes in the northern Gulf and can withstand temperatures as low as 7.5°C in experimental situations (Thomson and Lehner 1976). Due to the Gulf's relatively shallow depth at the central and northern portions, seasonal changes in currents and air temper-

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[1] Department of Ecology and Evolutionary Biology, University of California at Irvine, Irvine, California 92697, (714) 824-4332, e-mail: LAFERRY@UCI.EDU.

[2] Pharmacology and Toxicology Graduate Group, University of California at Davis, Davis, California 95616.

* Please address all correspondence.

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ature can bring predictable but drastically changing environments for Gulf species, forcing many to migrate (Thomson et al. 1987). The spotted sand bass typically has strong site affinity (Allen et al. 1995) and, therefore, must be able to acclimate to these changes readily. Such radical changes in temperature affect prey availability and the diet of the spotted sand bass must adjust accordingly.

Research on the diet of spotted sand bass from various regions has led to conflicting descriptions of prey types. Allen et al. (1995) reported that they feed mainly on crustaceans, bivalves (including infaunal species), and small fishes. Thomson and McKibbin (1986) and Thomson et al. (1987) similarly reported that they fed diurnally on small fishes and invertebrates. Ono (1992) included cephalopods as a primary prey group.

Bahia de Los Angeles, on the eastern side of the central Gulf, provides a unique environment in which to study diet of the spotted sand bass. These fish are year round residents there and are subjected to temperature changes of 9–14°C (Barnard and Grady 1968; Brinton et al. 1986). It is presumed that potential prey changes as a result of such temperature shifts. In this study we investigated how diet changed between two sampling periods characterized by radically different physical oceanographic conditions.

Materials and Methods

Spotted sand bass were collected 15–23 October (fall) 1992, and 27 March–2 April (spring) 1994 in Bahia de Los Angeles, Baja California, Mexico (Fig. 1). These two sampling periods were characterized by differences in sea surface temperature that were assumed to be correlated with the prey available to this species. The first sampling period was characterized as a warm period, with surface temperatures of 27°C. The second sampling period was a typical upwelling period, characterized by cool temperatures, around 19°C, and nutrient rich waters, as suggested by the abundance of subtidal and intertidal macroalgal species.

Nearshore stations (sites located at or near the mainland) were sampled while snorkeling or on SCUBA using pole spears, dip nets, and jigs, or by hook and line using surf poles. The nearshore stations and offshore stations (sites located around offshore islands) were also sampled by boat using hook and line with fresh bait (fish fillets and squid pieces) and artificial lures. Hooks of varying sizes were used to target a range of fish sizes. Care was taken to sample at similar depth ranges (generally shallow, 0–30 m; see Fig. 1) at all sites possible so as not to create a sampling bias.

Sites fished were grouped into regions according to location in the bay and effort was calculated for each region. Fishing effort was calculated by determining the number of hooks or pole spears in the water times the number of hours fished (=hook hours or spear hours).

Mass (g) and standard length (mm) were recorded for each specimen and the entire gastrointestinal tract removed for food habit analysis. Stomachs and intestines were everted and flushed clean with water and any contents preserved in 70% ethanol. Mouths and gill arches were also checked for regurgitated or recently consumed material. Whenever possible, the contents of both the stomach and the intestine were examined microscopically and identified to lowest possible taxa using various keys and taxonomic references (Day 1967; Farmer 1968; Schultz 1969; Keen 1971; Brusca 1980; Gotshall 1982; Kerstitch 1989; Hickman

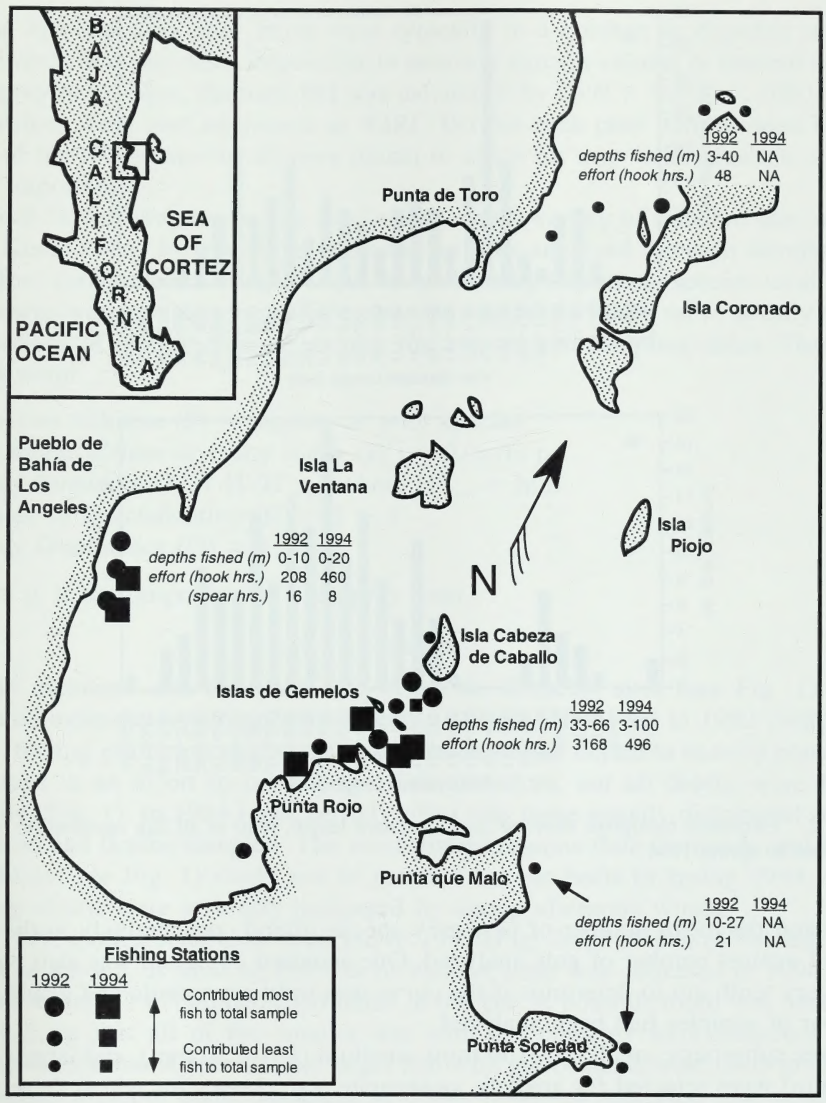

Fig. 1. Study site at Bahia de Los Angeles showing sites of fish capture and their grouping by major geographic features. Symbols indicate where fish were captured and size of the symbol indicates contribution of fish captured at that site to the total number of fish captured. Circles refer to sites sampled in fall 1992 and squares refer to sites sampled in spring 1994.

and McLean 1990). In most cases, the retention of hard parts was required to identify items to species, and many items could be identified only to family or order. Specific identifications were rare. Most fish remains could only be identified as fish remains from vertebrae or scales. Otoliths from fish prey were rarely recovered.

Cumulative prey curves were constructed for the entire 1992 and 1994 data sets to determine if an adequate number of fish had been collected to characterize the diet precisely. The order in which guts were analyzed was randomized ten

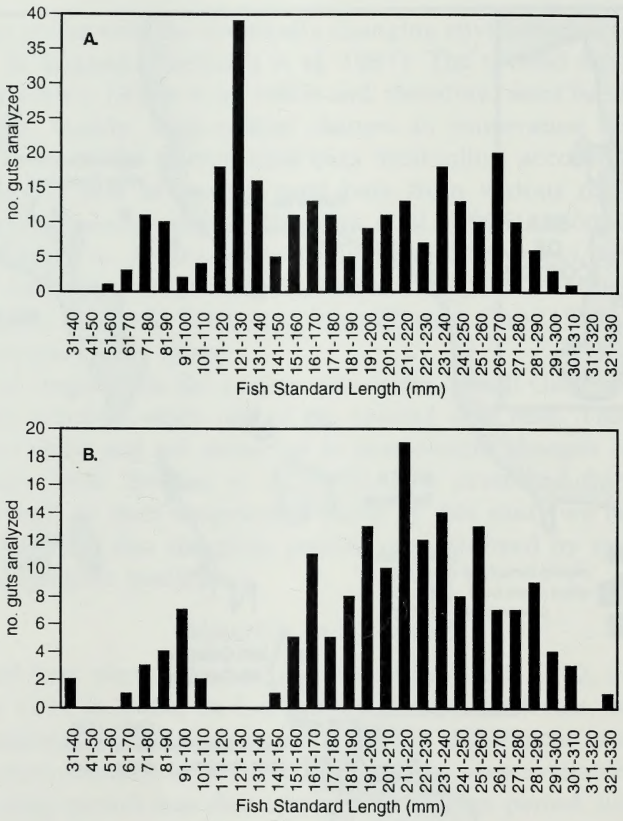

Fig. 2. Frequency histogram showing sizes (standard length, mm) of all fish captured in: A) fall 1992, and B) spring 1994.

times and the mean number of new prey species found consecutively in the guts plotted against number of guts analyzed. One standard deviation was also plotted for every tenth gut to determine if the curve was truly asymptotic and a sufficient number of samples had been analyzed.

Three subgroups; small (50–150 mm), medium (151–230 mm), and large (231–310 mm) were selected for analysis as separate size classes for which there were sufficient individuals and diet could be accurately assessed (Fig. 2a). Cumulative prey curves were also constructed to determine if there were enough guts analyzed to describe the feeding habits of each subgroup. In each case, the order in which prey were analyzed was randomized five times and a mean number of new prey species plotted against the number of guts analyzed. Standard deviations were also calculated.

Two dimensional indices of relative importance (IRI; Govoni et al. 1983) were calculated using the prey categories listed in Table 1 for all data and each size class. These were calculated by estimating percent number (%N) and percent frequency of occurrence (%FO) of each prey item in each gut, then calculating mean %N for each prey item among all guts analyzed for each size class and for all fish sampled for each sample year. This tends to prevent rare prey items, or items with long handling (i.e., digestion) times, from appearing overly important

in the diet. Because prey items were typically in a crushed or digested state, it was impractical and often impossible to measure percent volume or percent weight of a prey item. Thus, the total IRI was calculated by (%N × %FO) × 1000. Total IRI values were also expressed as %IRI (IRI for each prey item divided by the sum of the IRI values for all prey items) to allow for easy determination of prey item importance.

Mean %N of prey items was used to calculate a variety of standard diet indices (see Krebs 1988) for each size class and all guts analyzed for each sample year to allow comparison among groups. As previously indicated, species level identifications were not always possible, thus the computed values serve as only rough indications of dietary changes among size classes and sampling dates. These indices were:

Species richness (S) = number of prey species
Shannon-Weiner diversity index (H′) = $\Sigma(p_i * \ln p_i)$
Prey Evenness (J) = H'/H'_{max}, where $H'_{max} = \ln S$
Index of Specialization (R) = 1 − J
Prey Dominance (D) = Σp_i^2,

where p_i is the proportion of each prey item.

Results

The mainland and the Punta Rojo/Islas de Gemelos sites (see Fig. 1) were sampled extensively during both sampling periods. However, in 1992 (warm period), fishing effort was slightly biased towards deeper depths at heavily populated locations in an effort to catch larger fish, therefore, not all depths were fished equally (Fig. 1). In 1994 (cool period) effort was more equally distributed among all areas and depths sampled. The most distant regions (Isla Coronado and Punta que Malo; see Fig. 1) could not be reached by our boats in spring 1994, when fishing efforts were seriously hampered by strong afternoon winds.

Of 272 spotted sand bass collected in 1992 (Fig. 2a), 116 fish (43%) had food items in the gut. A total of 169 fish of various sizes was collected in 1994 (Fig. 2b), of which 97 (57%) had food items in the gut. A possible trend was observed in 1992, in that all of the smaller fish with gut contents were collected from shallow nearshore waters and the larger fish with gut contents were more prevalent in deeper, offshore sites. Sampling in 1994, however, indicated that small and large fish are found at both nearshore and offshore sites. Many small fish were collected at the offshore islands using light fishing tackle, and very large fish were found just off the mainland at moderate depths (10–15 m). Smaller fish, however, appear to inhabit shallower water regardless of location relative to the mainland or time of year.

Cumulative prey curves for all guts containing food items, based on the most definitive prey categories possible (Table 1), appeared only to slowly reach an asymptote (Fig. 3). New prey species were occurring regularly in the diet even after 100 guts had been analyzed. When the three size classes were analyzed independently for both sampling periods, however, most curves quickly approached an asymptote. This suggests that a sufficient number of fish were collected in each class for consideration as separate size classes (Fig. 4).

Obvious changes in diet between the sampling periods were observed. Fish

Table 1. All prey items identified to lowest possible taxa for fall 1992 and spring 1994 diets. Letters in parentheses refer to codes used in the IRI. Those items with codes are the most definitive levels of taxonomic characterization possible and are those used in cumulative prey curves.

Fall 1992	Spring 1994
(F) Pisces	(F) Pisces
(bl) Blenniidae	(ge) Gerreidae
Malacoctenus sp.	*Eucinostomus gracilis*
(Fr) Fish remains (unidentifiable)	(pl) Pleuronectidae
	Syacium ovale
	(clu) Clupeidae
	Harengula thrissina
	(Fr) Fish remains (unidentifiable)
Arthropoda	Arthropoda
(C) Crustacea	(C) Crustacea
Peracarida	Peracarida
(amp) Amphipoda	(amp) Amphipoda
	gammarid amphipod sp. 1
	gammarid amphipod sp. 2
(mys) Mysidacea	(mys) Mysidacea
	mysid sp. 1
	mysid sp. 2
	mysid sp. 3
(iso) Isopoda	(iso) Isopoda
unidentified sp.	unidentified sp.
	(tan) Tanaidacea
Eucaridea	Eucaridea
Decapoda	Decapoda
Natantia	Natantia
(car) Caridea	(car) Caridea
Alpheus sp.	unidentified shrimp
Palaemonella holmesi	
Periclimenes infraspinis	
unidentified shrimp	
Reptantia	Reptantia
	Astacura
	(thl) Thalassinoidea
	Calianassa sp.
Anomura	
(her) Paguroidea and Coenobitoidea	
Clibanarius digueti	
Diogenid hermit crab	
Pagurid hermit crab	
(gal) Galatheoidea	
Porcellanid crab	
(brc) Brachyura	(brc) Brachyura
Lepidotius occidentalis	*Lepidotius occidentalis*?
Xanthodes hebes	*Eurytium affine*?
Libinia mexicana	Xanthanid crab
Aratus pisonii	spider crabs
Xanthanid crab	
unidentified brachyuran crabs	
(Cr) Crustacean remains (unidentifiable)	
(E) Echinodermata	(E) Echinodermata
(oph) Ophiuroidea	(oph) Ophiuroidea
Ophioderma panamensi	*Ophiocoma alexandri*

Table 1. Continued.

Fall 1992	Spring 1994
Ophiocoma alexandri	unidentified brittle stars
Ophiothrix spiculata	
Ophionereis annulata	
unidentified brittle stars	
(hol) Holothuroidea	
Holothuria impatiens	
	(ech) Echinoidea
	unidentified urchin pieces
(M) Mollusca	(M) Mollusca
(chi) Polyplacophora	(chi) Polyplacophora
Lepidozona subtilis	unidentified chiton pieces
Chiton virgulatus	
Acanthochitonia sp.	
unidentified chitons	
(bvl) Bivalvia (Pelecypoda)	(bvl) Bivalvia (Pelecypoda)
Gari maxima	*Tivela* sp.
Tivela planulata	unidentified clam pieces
Tivela bryonensis	unidentified scallop pieces
Anadora grandis	
unidentified clams	
(gst) Gastropoda	(gst) Gastropoda
Littorina sp.	unidentified snail pieces
Tegula sp.	
Janthina sp.	
Anachis coronata	
Canthorus elegans	
Diodora saturnalis	
Melongena patula	
Collumbellid gastropod	
Turbinid gastropod (operculum and jaw plates)	
Trochaeid gastropod (operculum)	
Acmaeid limpet	
unidentified gastropods	
(cph) Cephalopoda	
squid beaks	
(Mr) Mollusc remains (unidentifiable)	
(A) Annelida	(A) Annelida
(wt) worm tubes	
(ply) Polychaeta	(ply) Polychaeta
Eunicid polychaete	Eunicid polychaete
	Aphrodita mexicana?
	(Ar) Annelid remains (unidentifiable)
(Ec) Echiura	(Ec) Echiura
	(oe) *Ochetostoma edax*?
(w) worms (unidentifiable)	
(O) other items	(O) other items
	(alg) algae pieces
	Sargassum sp.
(p) terrestrial plant material	
	(cor) coral
	Antipathes galapagensis

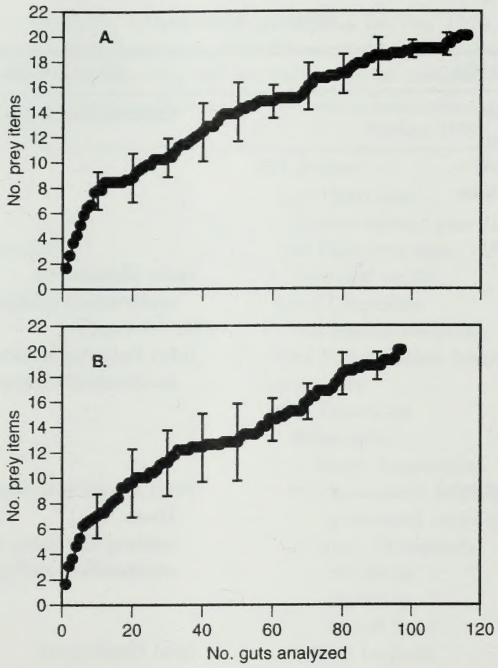

Fig. 3. Randomized cumulative prey curve for all fish with gut contents analyzed in: A) fall 1992 (warm period; n = 116); and B) spring 1994 (cool period; n = 97). Mean values are plotted. Error bars represent plus or minus one standard deviation. Lack of an asymptote on either graph is an indication of the diversity of diet within these larger groups, and the need to analyze diet within smaller functional groups of spotted sand bass.

remains, ophiuroids, and brachyuran crabs dominated the diet of spotted sand bass collected in fall 1992 (warm period; Fig. 5a, Appendix A). Crustaceans alone, however, dominated the diet of spotted sand bass collected in spring 1994 (cool period; Fig. 6a, Appendix B); making up >90% of the diet (by %IRI) for all fish groups except the smallest size class. This was due to an overwhelming abundance of mysid prey present in 1994 that were not found in fish collected in 1992. Molluscs were much less important than crustaceans as prey in both sampling periods collected; always contributing <10% to the diet (by %IRI) of any fish group. Annelids and other worms, as well as algae, coral, and terrestrial plant material were rare food items, generally <1% of the diet for any group of fishes. Diet was richer in number of species for most size classes, and more diverse in 1992 (Table 2). Diet in 1994 was lower in prey evenness and higher in index of specialization and prey dominance, indicating that one (mysids) or a few items had a large impact on the diet in 1994.

Within sampling periods diet shifts were evident among size classes. Small, medium, and large spotted sand bass consumed prey items in distinctly different proportions in 1992. Small spotted sand bass consumed fish and brachyuran crabs (both 26% of diet by %IRI) more often than ophiuroids and molluscs, which were proportionately similar, while annelids were absent altogether (Fig. 5b). Fish (48% by %IRI), natantian shrimp, and ophiuroids dominated the stomach contents of medium sized fish, while molluscs and annelids occurred less often (Fig. 5c). In

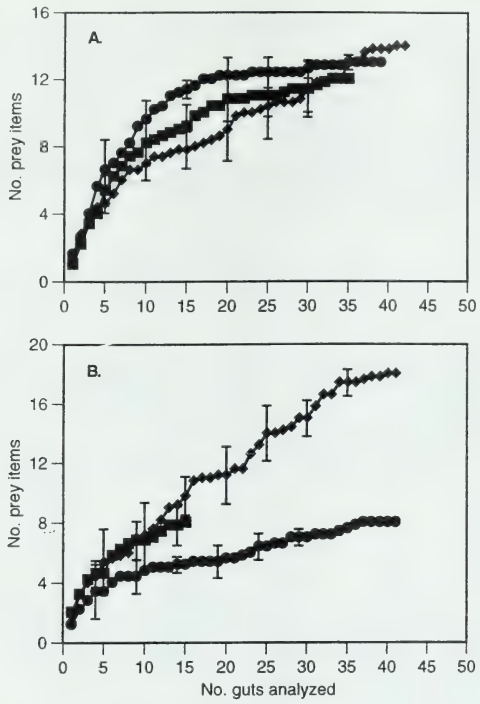

Fig. 4. Cumulative prey curves for: A) fall of 1992 (warm period); and B) spring of 1994 (cool period). Symbols are for (■) small spotted sand bass, 50–150 mm SL (n = 35); (●) medium spotted sand bass, 150–229 mm SL (n = 39); and (♦) large spotted sand bass, 230–310 mm SL (n = 42) collected in 1992, and for small (n = 15), medium (n = 41), and large spotted sand bass (n = 41) collected in 1994. Order of gut analysis was randomized five times and a mean number of prey items plotted. Error bars represent one plus or minus one standard deviation. Clear asymptotes indicate a sufficient sample size for precisely characterizing diet.

larger spotted sand bass, fish continued to be a common prey item (33% by %IRI); however, ophiuroids (50% by %IRI) made up the majority of the stomach contents (Fig. 5d).

In spring 1994, small sand bass ate primarily brachyuran crabs, mysids and gammarid amphipods (Fig. 6b), with crustaceans contributing 99% to the diet by %IRI. Molluscs and annelids were absent as prey in small spotted sand bass. Medium sized fish also consumed primarily crustaceans; however, this prey category was dominated almost exclusively by mysids (89% by %IRI; Fig. 6c). Ophiuroids, molluscs, annelids, and algae were found in the stomach contents infrequently. Fish as prey were more important in large sand bass (25% by %IRI) compared to small and medium size classes, although mysids (48% by %IRI) and brachyuran crabs (20% by %IRI) were still common prey items identified for this size class (Fig. 6d). Ophiuroids, molluscs, annelids, coral, and algae were found infrequently.

Among size classes, indices indicated that species richness was highest for the large size class, and prey evenness was highest for the small size class for both sampling periods (Table 2). However, diversity was also highest in the small size class for both periods (small and large size classes in 1994). Thus, while the large

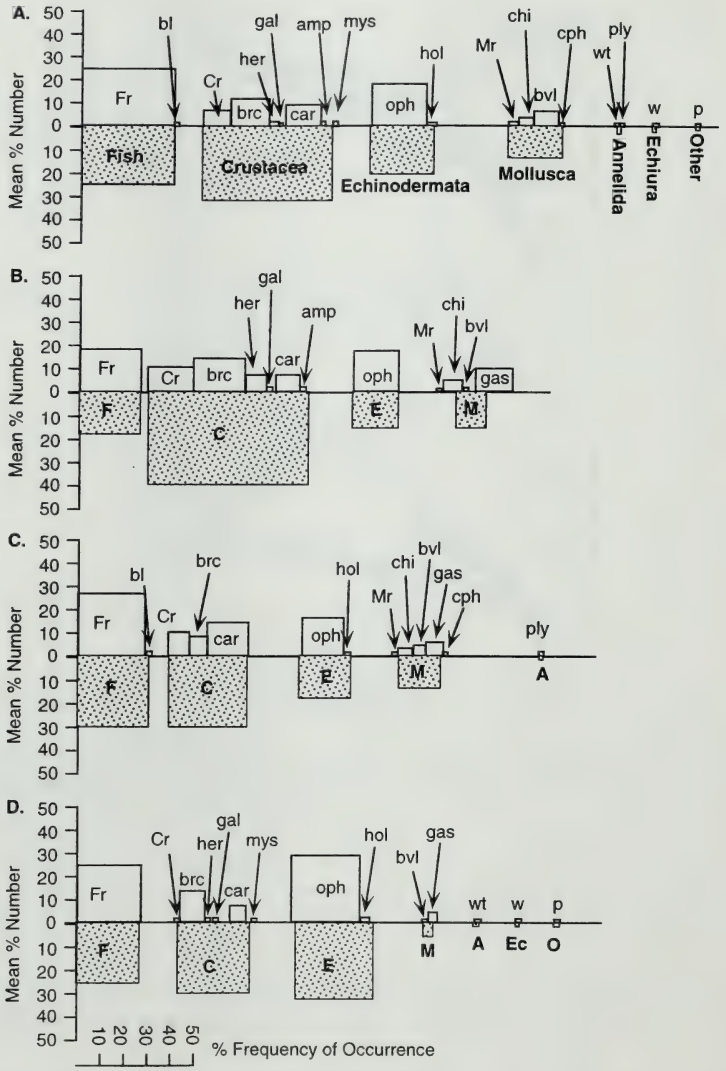

Fig. 5. Two-dimensional Index of Relative Importance (IRI) for: A) all fish; B) small fish (50–150 mm SL); C) medium fish (150–229 mm SL); and D) large fish (230–320 mm SL) with gut contents collected fall 1992 (warm period). Prey items are broken into the most specific level of identification possible on the positive vertical axis, and grouped by major taxonomic grouping on the negative vertical axis.

size class had the highest values for specialization and dominance in 1992, the medium size class had the highest values for specialization and dominance in 1994.

Discussion

The spotted sand bass, like many other serranids (see Love and Ebeling 1978; Hobson and Chess 1986; Watson and Davis 1989; Calif. Dept. of Fish and Game 1991), is clearly a classic generalist feeder. The lack of an asymptote for the

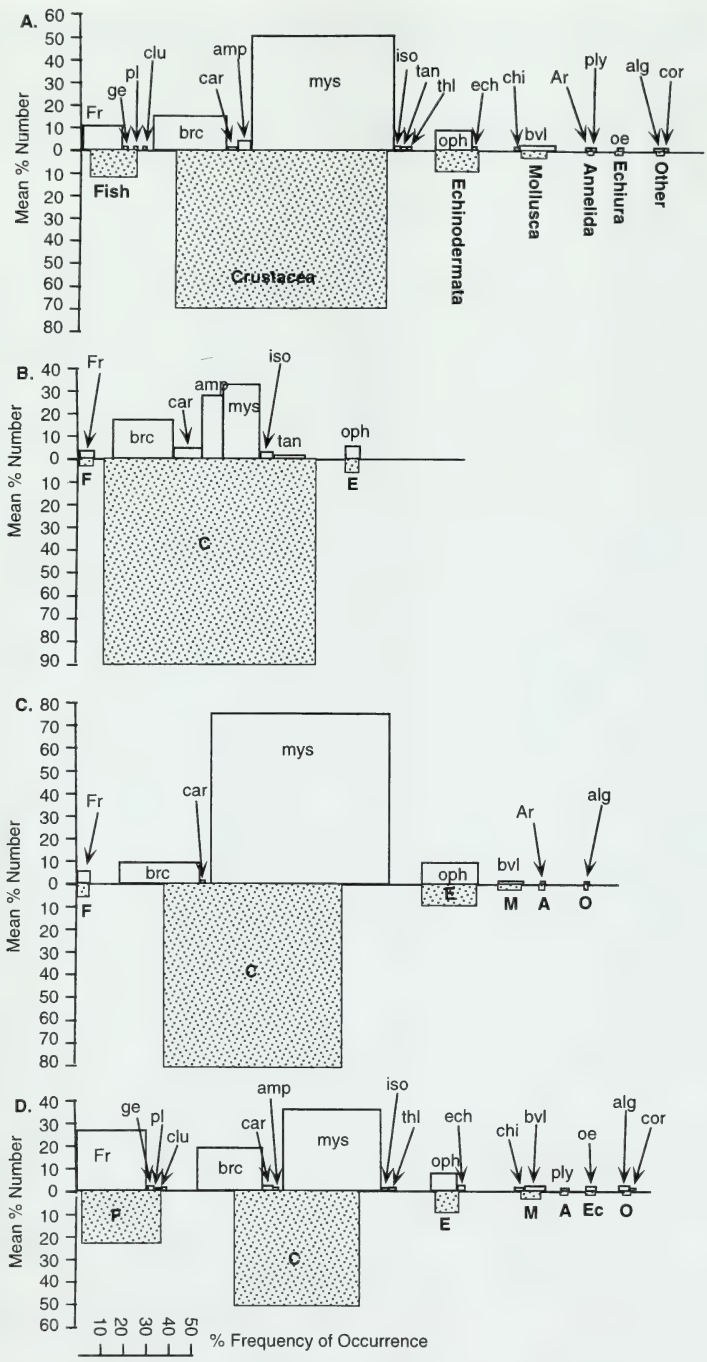

Fig. 6. Two-dimensional Index of Relative Importance (IRI) for: A) all fish; B) small fish (50–150 mm SL); C) medium fish (150–229 mm SL); and D) large fish (230–320 mm SL) with gut contents collected spring 1994 (cool period). Prey items are broken into the most specific level of identification possible on the positive vertical axis, and grouped by major taxonomic grouping on the negative vertical axis.

Table 2. Diet indices comparing diet at the most specific level of prey identification. Indices were calculated for all fish combined and for the three size classes of spotted sand bass collected during fall 1992 and spring 1994.

Index	S	H′	J	R	D
Fall 1992					
All fish	20.000	2.183	0.729	0.270	0.140
50–150 mm SL	12.000	2.134	0.859	0.140	0.108
151–230 mm SL	13.000	2.191	0.854	0.150	0.160
231–320 mm SL	14.000	1.895	0.718	0.280	0.187
Spring 1994					
All fish	20.000	1.675	0.559	0.440	0.279
50–150 mm SL	8.000	1.664	0.800	0.200	0.236
151–230 mm SL	8.000	0.999	0.480	0.520	0.557
231–320 mm SL	18.000	1.963	0.679	0.320	0.235

cumulative prey curves indicates that it takes a very large number of samples to precisely describe the diet of the spotted sand bass in Bahia de Los Angeles. This is a reflection of the broad diversity in diet of the spotted sand bass, and also indicates the importance of cumulative prey analyses in determining sample size sufficiency in feeding habits studies. Analysis of different size classes indicated that spotted sand bass diet varied ontogenetically. Within each size class there was much less variability than when all fish were analyzed as a group. This functional group approach (based on size) allowed trends to be more precisely detected both among size classes and between sampling periods.

As might be expected, spotted sand bass ate larger (i.e., fish) and faster moving prey items (i.e., mysids) as they increased in size. Other bass whose ranges overlap that of the spotted sand bass have been reported to consume fish in increasing number as size increases (Young 1963; Hobson 1965, 1968; Roberts et al. 1984; Holbrook and Schmitt 1988 a, b). However, Roberts et al. (1984) reported findings to the contrary: less mobile prey such as gastropods and polychaetes were most abundant in the diet of larger barred sand bass.

Less mobile prey, including benthic crustaceans and molluscs, made up proportionately more of the diet of smaller spotted sand bass in this study, suggesting that smaller spotted sand bass are less capable of catching more mobile prey. It is uncertain as to whether this is actually a function of fish size or location of capture. Differing prey availability in relation to fish location (i.e., inshore vs. offshore) might produce similar results; however, the concentrated effort to catch smaller fish at the offshore sites in spring 1994 indicates that fish are equally distributed among offshore and onshore sites and differences in diet are most likely due to some form of prey selection by spotted sand bass.

Roberts et al. (1984) also noted that mysids and amphipods were more dominant in the diet of the smaller (<240 mm) barred sand bass and were completely absent from the diet of larger bass (>320 mm). Although this was true for spotted sand bass in this study collected in 1992 (warm period), it did not hold true for larger fish collected in 1994 (cool period). In fact, to our knowledge, the overwhelming abundance of amphipods and mysids in the diet of large fish has not been reported for any serranid species in any waters (see, for example: Smith

1961; Randall 1967; Menni and Lopez 1979; Davis 1985; Parrish 1987; Dodrill et al. 1993; Hood et al. 1994; Pickett and Pawson 1994).

Although changes in diet among size classes were observed between both sampling periods, the changes in diet composition between sampling periods among all size classes were more striking. It is presumed that this change is due to seasonal changes in environment that altered prey availability. Availability of diet items has not been described completely; however, several previous surveys of the fauna of Bahia de Los Angeles support many of our suspicions. Barnard (1969) showed that the abundance of gammarid amphipods increased dramatically from fall to spring. Several samples considered to be confined to soft bottoms captured an abundance of gammarid amphipods. This environment should be the equivalent to that commonly exploited by the spotted sand bass. Throughout the bay benthic bivalves appeared more abundant in spring as well. Benthic gastropods did not appear to be clearly more abundant in spring or fall, but most species were only collected in one season or the other (Coan 1968). Interestingly, not all species of benthic polychaetes collected increased in abundance in spring, however, the distribution of all polychaete species analyzed was broader in spring than fall (Reish 1968).

The most striking observation from fall of 1992 (warm period) to spring of 1994 (cool period) in this study was the considerable alteration of environment in Bahia de Los Angeles. Sea surface temperature dropped nearly 7–8°C (from about 27°C to 19°C), and the intertidal cobblestone habitat was covered with various species of brown algae, including *Padina* sp. and *Colpomenia* sp. that were totally exposed at low tide. These were completely absent in the fall sampling season and contributed to the impression of a temperate reef community rather than the tropical community observed previously. Most of the colorful reef fishes, such as sergeant majors (*Abudefduf troschelii*) and Cortez damselfish (*Stegastes rectifraenum*) that dominated the rocky intertidal in fall of 1992, were scarce in spring of 1994. In fact, the only constant between the two sampling periods seemed to be the overwhelming abundance of spotted sand bass.

Why a species would remain in this widely changing environment rather than migrate throughout the Gulf like many other species is unknown. The spotted sand bass can survive in environments throughout the Gulf, as indicated by its distribution. It is worth noting that a dominant size class captured in fall 1992 (111–140 mm SL) is conspicuously absent from the sizes of bass collected in spring 1994. It is uncertain whether this is an indication of an unusual recruitment event. However, the continued presence of other sizes of spotted sand bass, still makes one wonder how a species can be versatile enough to survive such drastic changes in habitat. Hobson and Chess (1986) infer that the species composition in a given area is "strongly influenced by the presence of specific feeding opportunities." It would appear that the spotted sand bass can readily take advantage of any given feeding situation.

Spotted sand bass may be capable of modulatory multiplicity (Liem 1978, 1979), meaning they are capable of producing different kinematic sequences for capturing prey based on the type of prey and its mobility. This ability may improve with predatory experience (i.e., ontogenetically). Different-sized spotted sand bass may be utilizing wholly different regions of the mouth for prey capture. Although the functional morphology of feeding in spotted sand bass has not yet

been investigated, like other serranids they possess a myriad of structures possibly useful for catching and processing a wide diversity of prey items (see: Smith 1961; Vandewalle et al. 1992; Pickett and Pawson 1994). In the spotted sand bass we have noted a sharply toothed premaxilla, mandible, vomer, and palatine, as well as finely toothed gill arches (two distinct rows of teeth) and pharyngeal jaws. This might explain the broadly different types of prey found in different-sized spotted sand bass collected during the same sampling times.

The highly generalized mouth of the spotted sand bass may facilitate such an existence. This fish possesses features that allow it to successfully capture small mysids and fish nearly half its size. The long gill filaments and tiny teeth on the gill rakers might allow this fish to sieve prey out of the water. Fish caught often had hundreds of small crustaceans snagged on the gill apparatus. The sharp caniniform teeth on the dentary and premaxilla enable it to function as an active carnivore, capturing large, mobile prey. A large mouth with fleshy lips also allows the spotted sand bass to act as a picker-type feeder. It can easily consume hard shelled invertebrates that might be picked off the rocky substratum, probably crushing shells and exoskeletons with the crushing plates (pharyngeal jaws) at the back of the mouth. Although such crushing action by the pharyngeal jaws has not been previously recorded for a serranid (P. Wainwright, pers. comm.), all bivalves found in the gut were crushed at the apex. It would appear that spotted sand bass can effectively fill almost any available niche with ease.

Further evidence of this versatility is the striking difference between diets we described in both periods sampled in Bahia de Los Angeles, and diet described by Allen et al. (1995) of spotted sand bass caught off southern California. Their study represents what is, to date, the most comprehensive study of spotted sand bass diet, yet the much narrower range of prey items found off southern California (primarily infaunal bivalves and benthic crustaceans) overlaps little with the description of spotted sand bass diet from Bahia de Los Angeles. Although competition has not been specifically investigated, it is possible off southern California, since the spotted sand bass can be found with both the kelp bass and the barred sand bass. Several authors have shown that niche breadth is influenced by competition (Montgomery 1975; Werner and Hall 1976). In Bahia de Los Angeles, the only other common serranid, and probable competitor, was the gold spotted sand bass (*Paralabrax aurogutattus*), which was caught only in deeper water. It would seem that off southern California, the spotted sand bass, for whatever reason, is successfully utilizing quite different resources.

This plasticity in diet has been demonstrated for other species of serranids. Roberts et al. (1984) noted that gastropods, mysids, amphipods, and fish were consumed by barred sand bass off northern San Diego. The items with the highest IRI values were pelecypods and brachyurans. Roberts et al. (1984), however, pooled all diet items for the entire year sampled and did not analyze them on a seasonal basis. Kelp bass had the broadest diet and habitat distribution compared to rockfish species (*Sebastes*) off Santa Barbara, California (Love and Ebeling 1978). Kelp bass have been observed by divers using SCUBA to be opportunists, hovering in place until prey were detectable or vulnerable (Hobson and Chess 1986). However, the extreme richness and diversity of diet discovered here appears rare, even among serranids from other locations (see: Smith 1961; Randall

1967; Menni and Lopez 1979; Davis 1985; Parrish 1987; Dodrill et al. 1993; Hood et al. 1994; Pickett and Pawson 1994).

Further study on the seasonal changes in the diet of spotted sand bass of the Gulf of California are warranted. In this study, we targeted a localized study area during two different sampling periods. It was our goal, simply, to determine if diet changed. However, our confounding of season within sample year warrants a more comprehensive, long-term study of seasonal diet changes of this species that could be expanded throughout the Gulf. A study of this scope may provide additional support for our finding that this species can survive rather drastic seasonal habitat changes due to its ability to acclimate to changing prey availability.

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Appendix A. Prey items identified to their most definitive level and listed by prey item with mean %N, standard deviation (SD), %F, IRI and %IRI for: a) all fish collected; and b–d) the three size classes of spotted sand bass collected fall 1992.

Prey item	Mean %N	SD	%F	IRI	%IRI
a. all fish collected					
fish remains	0.245	0.407	0.371	90.819	0.419
blenniid fish	0.008	0.091	0.009	0.069	0.000
crustacean remains	0.076	0.226	0.155	11.793	0.054
brachyuran crabs	0.122	0.311	0.181	22.050	0.102
hermit crabs	0.025	0.143	0.043	1.078	0.005
galatheoid crabs	0.008	0.064	0.017	0.138	0.001
caridean shrimp	0.084	0.251	0.164	13.759	0.064
amphipods	0.008	0.091	0.009	0.069	0.000
mysids	0.004	0.046	0.009	0.034	0.000
ophiuroids	0.206	0.384	0.293	60.379	0.279
holothurians	0.008	0.091	0.034	0.276	0.001
mollusc remains	0.006	0.042	0.026	0.155	0.001
chitons (Polyplacophora)	0.038	0.173	0.052	1.966	0.009
bivalves	0.026	0.124	0.060	1.569	0.007
ophiuroids	0.075	0.217	0.164	12.284	0.057
cephalopods	0.003	0.030	0.009	0.026	0.000
worm tubes	0.004	0.046	0.009	0.034	0.000
polychaetes	0.008	0.091	0.009	0.069	0.000
echiuran worms	0.008	0.091	0.009	0.069	0.000
plant material	0.004	0.046	0.009	0.034	0.000
general level					
fish	0.246	0.407	0.371	91.041	0.243
crustaceans	0.326	0.416	0.552	179.916	0.479
echinoderms	0.220	0.039	0.328	71.972	0.192
molluscs	0.128	0.283	0.250	32.100	0.086
annelids	0.013	0.103	0.017	0.222	0.001
echiurians	0.008	0.091	0.009	0.072	0.000
other	0.004	0.046	0.009	0.036	0.000
b. fish 50–150 mm SL					
fish remains	0.167	0.354	0.286	47.714	0.265
crustacean remains	0.095	0.256	0.200	19.000	0.106
brachyuran crabs	0.164	0.332	0.286	46.857	0.261
hermit crabs	0.071	0.243	0.086	6.086	0.034
galatheoid crabs	0.014	0.083	0.029	0.400	0.002
caridean shrimp	0.074	0.238	0.114	8.457	0.047
amphipods	0.029	0.167	0.029	0.829	0.005
ophiuroids	0.136	0.301	0.200	27.200	0.151
mollusc remains	0.007	0.042	0.029	0.200	0.001
chitons	0.064	0.234	0.086	5.486	0.031
bivalves	0.014	0.083	0.029	0.400	0.002
gastropods	0.100	0.255	0.171	17.143	0.095
general level					
fish	0.167	0.354	0.286	47.762	0.129
crustaceans	0.398	0.407	0.686	272.685	0.736
echinoderms	0.136	0.305	0.200	27.140	0.073
molluscs	0.200	0.363	0.114	22.800	0.062
annelids	0.000	0.000	0.000	0.000	0.000
echiurians	0.000	0.000	0.000	0.000	0.000
other	0.000	0.000	0.000	0.000	0.000

Appendix A. Continued.

Prey item	Mean %N	SD	%F	IRI	%IRI
c. fish 151–230 mm SL					
fish remains	0.278	0.419	0.308	85.538	0.480
blenniid fish	0.025	0.158	0.026	0.650	0.004
crustacean remains	0.105	0.253	0.077	8.077	0.045
brachyuran crabs	0.089	0.274	0.077	6.846	0.038
caridean shrimp	0.137	0.289	0.179	24.590	0.138
ophiuroids	0.179	0.367	0.205	36.718	0.206
holothurians	0.012	0.079	0.026	0.308	0.002
mollusc remains	0.008	0.052	0.026	0.205	0.001
chitons	0.038	0.133	0.077	2.923	0.016
bivalves	0.051	0.181	0.051	2.615	0.015
gastropods	0.087	0.211	0.103	8.923	0.050
cephalopods	0.008	0.052	0.026	0.205	0.001
polychaetes	0.025	0.158	0.026	0.641	0.004
general level					
fish	0.278	0.419	0.308	85.624	0.325
crustaceans	0.305	0.402	0.333	101.665	0.386
echinoderms	0.201	0.373	0.256	51.379	0.195
molluscs	0.158	0.275	0.154	24.317	0.092
annelids	0.025	0.158	0.026	0.650	0.002
echiurians	0.000	0.000	0.000	0.000	0.000
other	0.000	0.000	0.000	0.000	0.000
d. fish 231–310 mm SL					
fish remains	0.242	0.409	0.262	63.355	0.333
crustacean remains	0.008	0.050	0.024	0.190	0.001
brachyuran crabs	0.143	0.350	0.119	17.024	0.089
hermit crabs	0.012	0.073	0.024	0.286	0.002
galatheoid crabs	0.012	0.076	0.024	0.286	0.002
caridean shrimp	0.083	0.265	0.095	7.905	0.042
mysids	0.012	0.076	0.024	0.286	0.002
ophiuroids	0.309	0.451	0.310	95.643	0.502
holothurians	0.024	0.153	0.048	1.143	0.006
bivalves	0.012	0.076	0.024	0.286	0.002
gastropods	0.060	0.195	0.048	2.857	0.015
worm tubes	0.012	0.076	0.024	0.286	0.002
echiuran worms	0.024	0.153	0.024	0.571	0.003
plant material	0.012	0.076	0.024	0.286	0.002
general level					
fish	0.242	0.409	0.262	63.378	0.238
crustaceans	0.270	0.415	0.310	83.638	0.314
echinoderms	0.345	0.463	0.333	114.952	0.431
molluscs	0.070	0.207	0.048	3.350	0.013
annelids	0.012	0.076	0.024	0.288	0.001
echiurians	0.024	0.153	0.024	0.576	0.002
other	0.012	0.076	0.024	0.288	0.001

Appendix B. Prey items identified to their most definitive level and listed by prey item with mean %N, standard deviation (SD), %F, IRI and %IRI for: a) all fish collected; and b–d) the three size classes of spotted sand bass collected spring 1994.

Prey item	Mean %N	SD	%F	IRI	%IRI
a. all fish collected					
fish remains	0.104	0.281	0.155	16.098	0.045
gerreids (mojarra)	0.010	0.100	0.010	0.103	0.000
pleuronectids (flatfish)	0.003	0.033	0.010	0.034	0.000
clupeids (herring)	0.005	0.050	0.010	0.053	0.000
brachyuran crabs	0.143	0.309	0.330	47.242	0.132
caridean shrimp	0.017	0.093	0.052	0.876	0.002
amphipods	0.045	0.193	0.062	2.804	0.008
mysids	0.486	0.472	0.557	270.557	0.755
isopods	0.008	0.055	0.021	0.155	0.000
tanaids	0.002	0.017	0.021	0.035	0.000
thalassinoids	0.002	0.022	0.010	0.023	0.000
ophiuroids	0.090	0.265	0.175	15.773	0.044
echinoids	0.010	0.100	0.010	0.103	0.000
chitons	0.000	0.004	0.010	0.004	0.000
bivalves	0.021	0.123	0.196	4.192	0.012
annelid remains	0.003	0.033	0.010	0.034	0.000
polychaetes	0.000	0.004	0.010	0.004	0.000
echiuran worms	0.003	0.025	0.021	0.062	0.000
algae	0.007	0.051	0.031	0.213	0.001
coral	0.005	0.050	0.010	0.053	0.000
general level					
fish	0.104	0.281	0.190	19.779	0.032
crustaceans	0.723	0.425	0.800	578.240	0.953
echinoderms	0.093	0.270	0.190	17.689	0.029
molluscs	0.022	0.125	0.080	1.776	0.003
annelids	0.004	0.034	0.020	0.074	0.000
echiurians	0.003	0.025	0.021	0.063	0.000
other	0.012	0.072	0.040	0.492	0.001
b. fish 50–150 mm SL					
fish remains	0.035	0.129	0.067	2.345	0.018
brachyuran crabs	0.177	0.341	0.267	47.280	0.367
caridean shrimp	0.050	0.167	0.133	6.667	0.052
amphipods	0.292	0.419	0.067	19.467	0.151
mysids	0.331	0.452	0.133	44.133	0.343
isopods	0.033	0.125	0.067	2.200	0.017
tanaids	0.017	0.046	0.133	2.267	0.018
ophiuroids	0.067	0.170	0.067	4.467	0.035
general level					
fish	0.036	0.129	0.067	2.392	0.003
crustaceans	0.900	0.280	0.909	818.100	0.992
echinoderms	0.067	0.170	0.067	4.489	0.005
molluscs	0.000	0.000	0.000	0.000	0.000
annelids	0.000	0.000	0.000	0.000	0.000
echiurians	0.000	0.000	0.000	0.000	0.000
other	0.000	0.000	0.000	0.000	0.000

Appendix B. Continued.

Prey item	Mean %N	SD	%F	IRI	%IRI
c. fish 150–230 mm SL					
fish remains	0.055	0.306	0.049	2.683	0.004
brachyuran crabs	0.100	0.262	0.366	36.585	0.056
caridean shrimp	0.001	0.008	0.024	0.024	0.000
mysids	0.729	0.399	0.805	586.756	0.895
ophiuroids	0.112	0.296	0.244	27.317	0.042
bivalves	0.019	0.103	0.098	1.854	0.003
annelid remains	0.008	0.051	0.024	0.195	0.000
algae	0.002	0.012	0.024	0.049	0.000
general level					
fish	0.055	0.306	0.049	2.695	0.004
crustaceans	0.829	0.357	0.731	605.634	0.950
echinoderms	0.112	0.296	0.244	27.317	0.043
molluscs	0.019	0.103	0.098	1.854	0.003
annelids	0.008	0.051	0.024	0.195	0.000
echiurians	0.000	0.000	0.000	0.000	0.000
other	0.002	0.012	0.024	0.048	0.000
d. fish 231–310 mm SL					
fish remains	0.268	0.449	0.268	71.980	0.251
gerreids (mojarra)	0.024	0.156	0.024	0.595	0.002
pleuronectids (flatfish)	0.008	0.052	0.024	0.195	0.001
clupeids (herring)	0.012	0.078	0.024	0.295	0.001
brachyuran crabs	0.197	0.380	0.293	57.659	0.201
caridean shrimp	0.023	0.102	0.049	1.122	0.004
amphipods	0.004	0.023	0.024	0.098	0.000
mysids	0.336	0.456	0.415	139.317	0.486
isopods	0.006	0.039	0.024	0.146	0.001
thalassinoids	0.005	0.034	0.024	0.122	0.000
ophiuroids	0.086	0.268	0.122	10.488	0.037
echinoids	0.024	0.154	0.024	0.585	0.002
chitons	0.001	0.006	0.024	0.022	0.000
bivalves	0.033	0.161	0.073	2.415	0.008
polychaetes	0.001	0.005	0.024	0.017	0.000
echiuran worms	0.007	0.039	0.049	0.341	0.001
algae	0.015	0.079	0.049	0.732	0.003
coral	0.012	0.077	0.024	0.293	0.001
general level					
fish	0.235	0.395	0.341	80.135	0.214
crustaceans	0.530	0.487	0.531	281.642	0.751
echinoderms	0.111	0.306	0.094	10.406	0.028
molluscs	0.034	0.163	0.063	2.148	0.006
annelids	0.001	0.005	0.024	0.017	0.000
echiurids	0.007	0.039	0.049	0.341	0.001
other	0.015	0.079	0.024	0.348	0.001

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The Relationship between an Ocean Outfall and Sediment Properties from the San Pedro Shelf, California

Don Maurer[1] and Hai Nguyen[2]

[1]*Department of Biological Sciences, California State University, Long Beach, Long Beach, California 90840*
[2]*County Sanitation Districts of Orange County, 10844 Ellis Avenue, Fountain Valley, California 92708*

Abstract.—Sediment properties (skewness, kurtosis, dispersion, % gravel, % sand, % silt, % total organic carbon with emphasis on % clay were examined from 1985 to 1993 from the San Pedro Shelf, California. The hypothesis tested here was that an ocean outfall has not significantly altered local sediment properties through time. The hypothesis was rejected. The 1993 peak in % clay for all stations was probably related to above average rainfall and runoff associated with the 1992–1993 El Niño.

Bathymetry and hydrography have major effects on sediment distribution in the ocean (Basford et al. 1993). The submarine topography of the shelf and slope off southern California is so distinctive with its basins and ridges that it is termed the continental borderland. Because these basins are viewed as sediment traps for organic matter, and thus precursors as source rocks for the formation of oil, the geology and sediments of the borderland have been extensively studied (Emery 1960; Schwalbach and Gorsline 1985). The sediments on the San Pedro Shelf have been studied in detail (Moore 1954; Gorsline and Grant 1972; Karl 1976; Drake et al. 1985). Based on these studies surface sediments on the San Pedro Shelf were grouped into relict and modern end members along with a range of their mixtures. The southeast portion of the shelf depicted in Drake et al. (1985), bounded on the west by the San Gabriel Canyon and on the east by the Newport Canyon, is the special focus of this account (Fig. 1) which adds to the considerable body of knowledge for the area by presenting a unique set of long-term annual data (1985–1993).

Interaction between geological features and hydrology also influences sediment transport and sediment distribution along the shelf (Johnson 1956; Wolf 1969; Grant and Madsen 1979). Still other interactions of significance (storms, longshore currents, upwelling, turbidity currents, earthquakes, landslides) also affect the fate of sediments in the coastal zone (Komar 1976; Vercoutre et al. 1987; McHugh et al. 1992). Additional factors contributing to sediment composition, transport and deposition involve source rock, watershed characteristics and fluvial runoff (Hamilton 1993). The relationship between fluvial runoff and sediment transport has received wide attention throughout the long California coastline (Schwalbach and Gorsline 1985; Leithold 1989). Rodolfo (1970), Rice et al. (1976), Brownlie and Taylor (1981), and Stone and Chang (1987) are some of the studies focusing on southern California.

In addition to natural processes, there are a variety of anthropogenic activities

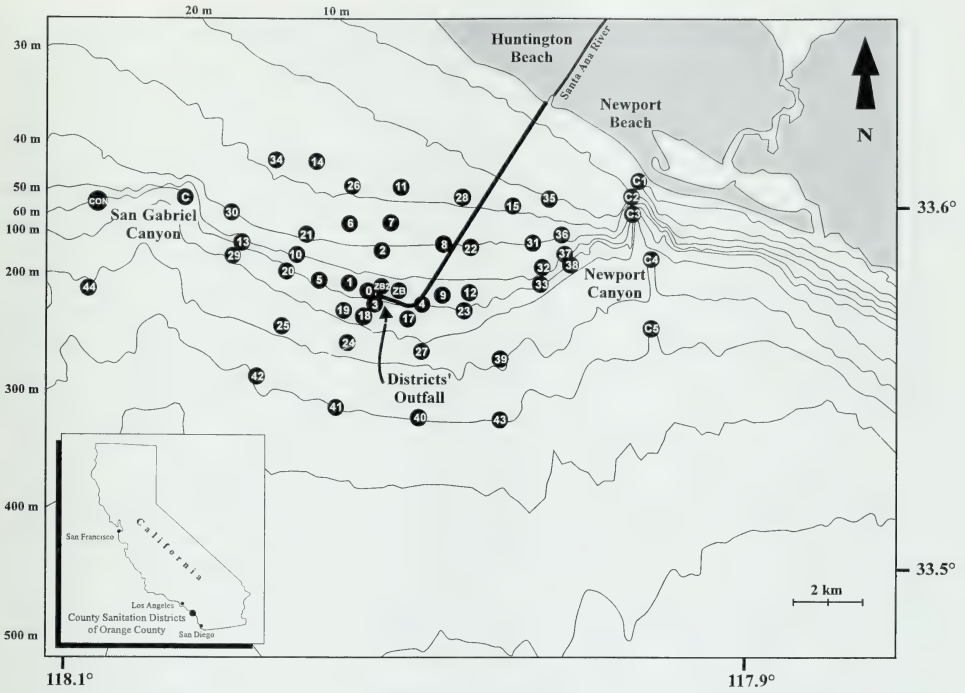

Fig. 1. Station location map for sediment samples, San Pedro Shelf, California 1985–1993.

(water diversion projects, dam and reservoir construction, irrigation practices, municipal and industrial wastewater discharge, ocean dumping, dredge disposal, drilling fluids and cuttings discharge) which directly influence sediment size, composition, distribution and quality on the continental shelf (Eisma 1973, 1990; Dyer 1984; McLaren and Little 1987; Halim 1991; Anderson et al. 1993; Abu-Hilal 1994; Bookman et al. 1994). Further, the relationship between sediment particle size, in particular fine size fractions, and certain particulate contaminants is well documented (Venkatesan et al. 1980; Finney and Huh 1989; Krumgalz 1989; Szefer et al. 1995). Of particular interest is the role of ocean outfalls in potentially altering local sedimentary properties.

The Southern California Bight (SCB) presently accommodates four major ocean outfalls (City of San Diego, Orange County, Los Angeles County, City of Los Angeles). These outfalls annually discharge 1.6×10^{12} l of treated wastewater containing 8.3×10^{4} t of suspended solids (Anderson et al. 1993). Since a wide variety of organic and inorganic contaminants are associated with the suspended solids deposited in the ocean, contaminant loads are the subject of considerable study in the SCB (Anderson et al. 1993). Any significant change in sediment properties from natural processes and/or anthropogenic activities, may affect their affinity to accumulate particulate contaminants, influencing their composition and quality, and, ultimately their interaction with community structure and function of soft-bottom macrobenthos. Hamilton (1993) makes a strong case that the logical and essential information which usually accompanies the description and identification of biota should also be provided for sediments, but rarely is.

The County Sanitation Districts of Orange County, California (Districts) op-

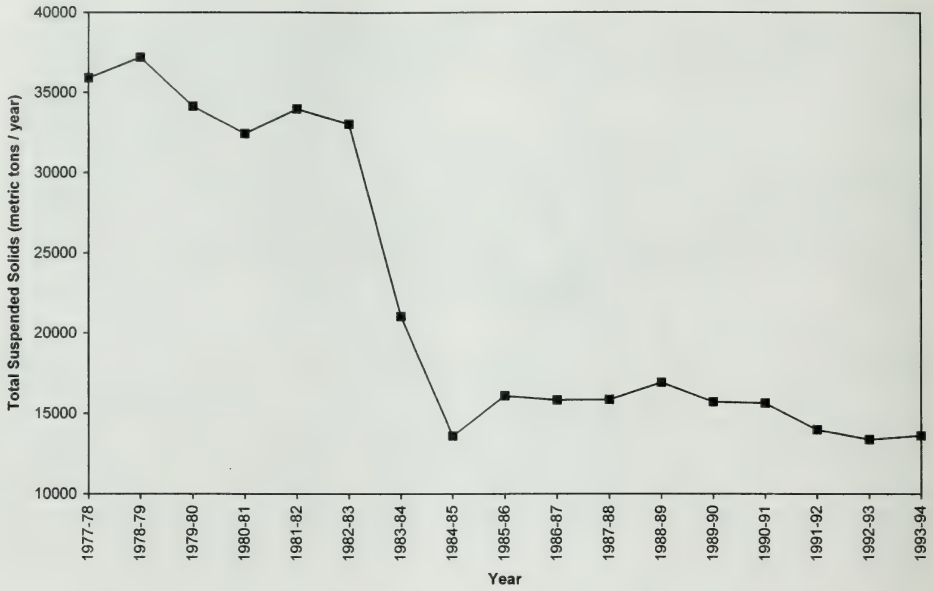

Fig. 2. Yearly mass emissions for total suspended solids, Districts' ocean outfall July 1977 to June 1994.

erates a 8 km long, multi-port (500) diffuser, ocean outfall, daily discharging 9.58 $\times$ 10^8 l of treated (50% advanced primary and 50% secondary) domestic (80%) and industrial (20%) effluent on the San Pedro Shelf (Fig. 1). From 1977 through 1994 approximately 3.6 $\times$ 10^5 t of total suspended solids (TSS) have been discharged from the outfall to the shelf (Fig. 2). While treatment changes caused a major reduction in discharge of TSS between 1982 and 1983, mass emissions of TSS have been relatively stable from 1985 through 1994 hovering about 1.5 $\times$ 10^4 t·yr^{-1} (Fig. 2).

The Districts applied for a National Pollutant Discharge Elimination System (NPDES) permit under Section 301(h) of the Federal Clean Waters Act (CWA) to discharge wastewaters, which have received less than full secondary treatment. As a part of its 301 (h) monitoring program, the Districts have conducted an extensive series of studies on the potential effects of wastewater discharges on the ocean habitat. Results of these studies are presented in detail in annual reports and publications (Districts 1988, 1990, 1991, 1992, 1993, 1994; Gerlinger et al. 1993; Robertson et al. 1993). These accounts include descriptions of a large set of annual and seasonal sediment samples. In view of the 1000s of tons of TSS released via the outfall to the shelf, this discharge may be expected to alter the sediment properties of areas adjacent to the outfall. The purpose of this account is to describe long-term changes in sediment properties from the study area. The hypothesis tested here is that the Districts' ocean outfall has not significantly altered local sediment properties through time (1985–1993).

Methods

Field.—All benthic sampling used a modified Van Veen grab (0.1 m^2). Station locations were determined by LORAN C. Fifty-three stations ranging in depth from 30–300 m were designated for monitoring sediment in the study area (Fig.

1). The latter encompasses approximately 144 km^2 and is bounded by two submarine canyons, the San Gabriel Canyon on the west and the Newport Canyon on the east. Thirteen 60 m stations were sampled quarterly (winter, spring, summer, fall) with three grabs to assess seasonal fluctuations in abiotic and biotic properties and to focus on spatial effects from the outfall (reducing variation from changes attributed to depth). The remaining 40 stations are sampled by one grab annually to provide regional coverage totaling 53 stations (Fig. 1). These data cover the period 1985 through 1993.

Laboratory.—For the grain size analysis, a 20–30 g subsample collected from the top 2 cm of the grab sample was transferred to a 240 ml bottle, mixed with 150 ml of deflocculent (sodium hexametaphosphate), and allowed to stand overnight (Districts 1994). The sediment sample was then sieved through a 64 μ sieve (U.S.A. Standard Testing Sieve No. 230) to separate the sand fraction from the silt-clay fraction. The sand fraction was dried and shaken through a series of eleven U.S.A. Standard Testing Sieves, which range in intervals from -1.0 to >9.0. Each retained fraction was then weighed. The silt-clay fraction, from 4.0 to 9.0 ϕ, was measured in whole ϕ intervals by standard pipette timed-withdrawal methods, and weights for each ϕ interval were calculated. These two methods provided fractional weights for each interval measured for computer input and analysis. A computer program performed the grain size distribution analysis and produced values for median ϕ size, mean ϕ size, dispersion, skewness, kurtosis, % gravel, % sand, % silt, % clay, and total organic carbon (TOC) (Districts 1994). TOC was quantified using an Oceanography International model 524-B organic carbon analyzer, with a Horiba model PIR infrared CO_2 gas analyzer and an ampule sealing unit (Oceanography International). Samples were dried and ground to ensure complete oxidation of the organic matter (Districts 1989). Samples for TOC were only collected since July 1987.

Results

General.—Annual sediment properties from 1985 to 1993 were averaged and tabulated (Table 1). Based on mean values of median ϕ, skewness, and kurtosis the study area (Fig. 1) can be characterized as consisting of very well sorted, strongly fine-skewed, very leptokurtic, very fine sand following Folk's (1968) guidelines. The mean median ϕ values (Table 1) certainly reflect the overall classification of very fine sand according to the Wentworth Scale adopted by Folk (1968). The coefficient of variation (cv) for all sediment properties was very small with % gravel producing the largest spread (4.7%). Sediment properties changed with water depth and proximity to the canyons.

Spatial.—Annual sediment properties from 1985 to 1993 were averaged and depicted on contour maps for the study area yielding the following patterns (Fig. 3). Percent gravel ranged from 0.0 to 5.0 with a mean of 0.1% (Table 1). Gravel generally provides an infrequent size fraction to sediments on this portion of the San Pedro Shelf. Highest values of gravel were recorded immediately downslope from the outfall (Fig. 3A).

Percent sand ranged from 1.8 to 92.1 with a mean of 58.8% (Table 1). Sand sized particles dominated the study area. Sand concentration was highest in the northwest section (>90%) and gradually decreased with depth and towards the Newport Canyon in the east and southeast to less than 1.0% (Fig. 3B).

Table 1. Descriptive statistics for annual sediment properties from the San Pedro Shelf, California 1985–1993.

Statistics	Gravel	Sand	Silt	Clay	TOC	Med. ϕ	Disp.	Skew.	Kurt.
mean	0.1	58.8	32.1	9.1	0.7	4.0	1.2	0.3	1.9
min	0.0	1.8	5.1	0.1	0.2	2.4	0.4	−0.1	0.6
max	5.0	92.1	75.1	44.1	2.4	7.5	3.2	0.8	4.2
SD	0.3	26.4	20.1	7.6	0.5	0.9	0.7	0.2	0.7
N	477	477	477	477	371	477	477	477	224
C.V.	4.7	0.4	0.6	0.8	0.7	0.2	0.6	0.5	0.3
Statistics	ϕ = −1	ϕ = −0.5	ϕ = 0	ϕ = 0.5	ϕ = 1	ϕ = 1.5	ϕ = 2	ϕ = 2.5	ϕ = 3
mean	0.1	0.0	0.1	0.1	0.3	0.7	0.9	2.1	7.5
min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
max	5.0	1.0	2.9	5.6	9.0	15.7	19.2	26.7	36.3
SD	0.3	0.1	0.2	0.4	0.8	1.7	2.1	3.8	0.4
N	477	477	477	477	477	477	477	477	477
C.V.	4.7	2.5	2.5	2.6	2.7	2.3	2.3	1.8	1.0
Statistics	ϕ = 3.5	ϕ = 4	ϕ = 5	ϕ = 6	ϕ = 7	ϕ = 8	ϕ = 9	ϕ > 9	
mean	23.0	24.1	18.9	6.8	4.1	2.3	1.7	7.4	
min	0.3	0.9	2.7	0.0	0.0	0.0	0.0	0.0	
max	56.0	72.0	43.6	37.8	27.4	12.9	10.0	36.9	
SD	14.4	11.8	9.4	7.8	5.2	2.8	1.8	6.2	
N	477	477	477	477	477	477	477	477	
C.V.	0.6	0.5	0.5	1.1	1.3	1.2	1.1	0.8	

Legend: Gravel, Sand, Silt, Clay, TOC = %; Med. = Median, Skew. = Skewness, Kurt. = Kurtosis, −1.0 to >9.0 = ϕ values.

Percent sand and gravel were also relatively high around the outfall, and in particular downslope and downcoast (Fig. 3A–B). To provide support and stability to the outfall, constructors placed ballast rock along side of the pipe. In addition to ballast rock, the outfall itself provides a firm substratum for a variety of hard substrate, epifaunal organisms. Extensive videotaping of the outfall for maintenance purposes has revealed substantial growth and development of flora and fauna (Siverts and Siverts 1994). As epifaunal organisms die and decay, deposition of barnacle plates and shell hash (molluscs and calcareous worm tubes) increases the % sand and gravel size fractions in the zone of initial dilution (ZID) above that in the surrounding area. Finally, erosion of relict in-situ sediments releases fossil shells which also contribute to the shell hash (Districts 1994).

Patterns for % silt, clay and TOC were inversely related to % sand. Percent silt, clay and TOC ranged from 5.1 to 75.1, 0.1 to 44.1 and 0.2 to 2.4, respectively, with mean values of 32.1%, 9.1% and 0.7% (Table 1). Silt and clay peaked with depth and in the Newport Canyon and generally decreased towards the northwest (Fig. 3C–D). Although TOC generally reflected the same pattern as silt and clay, concentration of TOC ranged from 0.5–1.0% at Station 0 (outfall) (Fig. 3E).

Temporal.—Average annual (N = 53) sediment characteristics from 1985 to 1993 were examined with ANOVA. Based on these analyses significant ($P < 0.05$) differences were found for kurtosis, skewness, % clay, and ϕ values for 0.0,

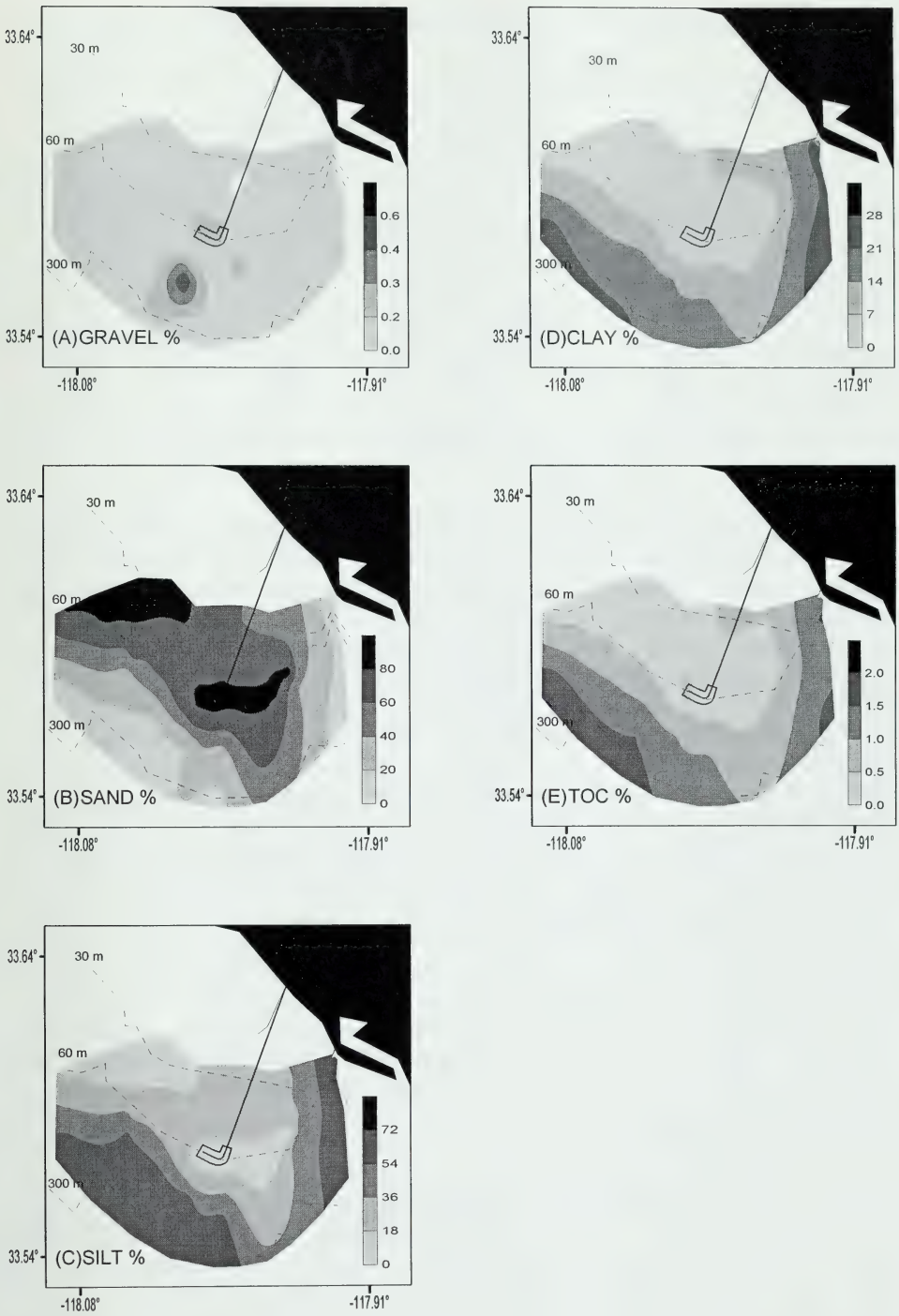

Fig. 3. Contour maps of percent, (A) = Gravel, (B) = Sand, (C) = Silt, (D) = Clay, (E) = TOC, San Pedro Shelf, California 1985–1993.

Table 2. ANOVA for significant annual sediment properties from the San Pedro Shelf, California 1985–1993.

	Source	Sum of squares	df	Mean square	F-ratio	*P*
Clay	year	1163.8	8	145.5	2.6	0.01
	error	26,523.0	468	56.7		
$\phi = 0$	year	1.0	8	0.1	3.6	0.00
	error	15.9	468	0.0		
$\phi = 0.5$	year	2.6	8	0.3	2.3	0.02
	error	66.9	468	0.1		
$\phi > 9$	year	1069.9	8	133.7	3.7	0.00
	error	17,071.9	468	36.5		
Kurtosis	year	24.3	8	3.0	8.9	0.00
	error	73.5	215	0.3		
Skewness	year	0.5	8	0.1	2.3	0.00
	error	12.1	468	0.0		

0.5 and >9.0 from 1985 through 1993 (Table 2). For purposes of this account, we focused on % clay with $\phi > 9.0$ defining medium clay according to the Wentworth Scale. Average % clay ranged annually from 5.5% to 11.7% throughout the study area between 1985 and 1993 (Fig. 4A). Percent clay peaked in 1993 for the annual summer survey. The largest increase occurred between 1985 and 1986 with a second increase between 1991 and 1993 (Fig. 4A). Tukey's multiple comparison test showed that % clay in 1988 and 1993 was significantly ($P < 0.05$) higher than in 1985. Regression of % clay through time was not significant for all 53 stations (Fig. 4A).

Since Station 0 (outfall) represents the major locus of discharge of TSS, the record of % clay associated with this station is most pertinent. Although there were some seasonal fluctuations in % clay at Station 0 from 1985 through 1993, there was a progressive increase through time (Fig. 4B). Regression analysis of percent clay through time was statistically significant ($r^2 = 0.79$, $P < 0.001$). The major peak in % clay recorded for the regional survey in 1993 was also recorded at Station 0 (Fig. 4B). For purposes of comparison with Station 0, % clay at Station CON, the conventional benthic reference station for this study area, was depicted (Fig. 4C). Percent clay at Station CON also showed seasonal fluctuations. Regression analysis ($r^2 = 0.08$) of percent clay through time was not statistically significant (Fig. 4C). However, the 1986 value was considered an outlier. When the regression analysis was computed without the 1986 value, the relationship was statistically significant ($r^2 = 0.65$, $P < 0.015$).

This comparison was expanded to include other 60 m stations (Fig. 5). The deviation of % clay at twelve 60 m stations from 1985 norm was prepared (Fig. 5). From 1986 through 1989 there was considerable fluctuation from the 1985 norm in particular at nearfield stations and occasionally at a farfield station in 1988 (Fig. 5). From 1989 through 1993 % clay deviated only slightly.

Discussion.—The hypothesis posed at the outset stated that the Districts' outfall has not significantly altered local sediment properties for 1985 through 1993 on the San Pedro Shelf. While there was a significant increase in % clay through time at the outfall, there was a significant coincidental regional peak in 1993 at

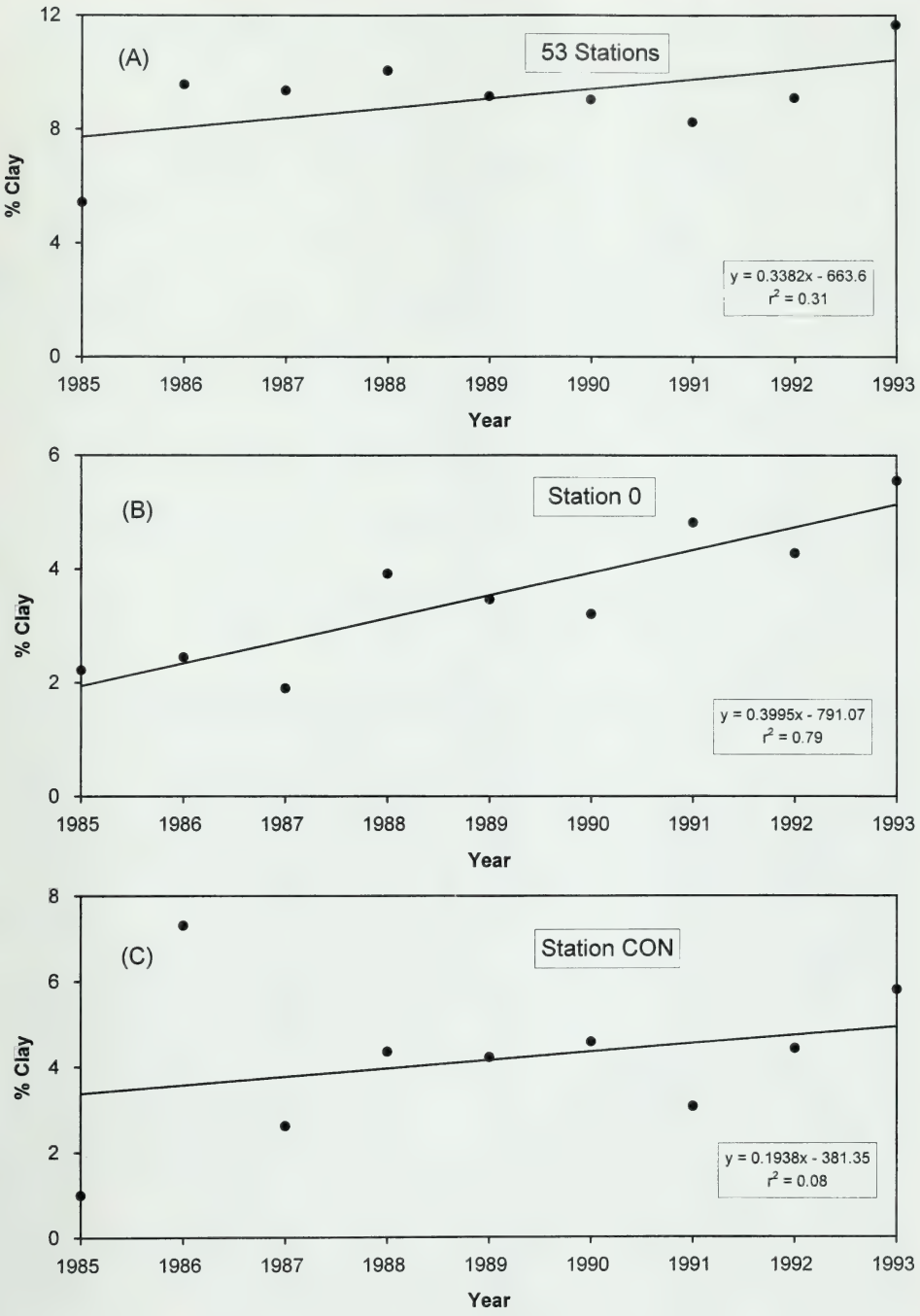

Fig. 4. (A) = Average annual clay, San Pedro, California 1985–1993, (B) = Average annual % Clay Station 0, (C) = Average annual % clay Station CON.

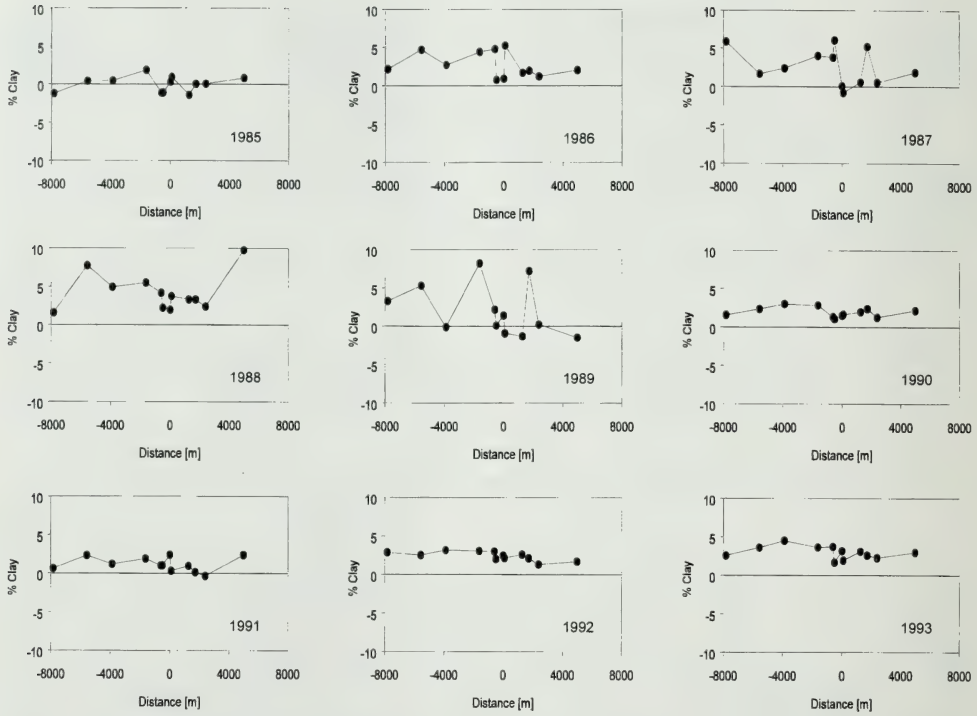

Fig. 5. Deviation of % clay at twelve 60 m stations from 1985 to 1993 with 1985 as the norm.

all stations (Fig. 1). Rainfall data from several onshore rain gauge stations were obtained for 1985–1993 (Fig. 6). Although there were small differences in rainfall across stations, the patterns were similar. A drought period is evident from 1986 through 1990 (Fig. 6). The 1992 peak rainfall was associated with El Niño conditions in the SCB as was a similar (1982–1983) peak rainfall event. The effects of winter storms and rainfall on the relationship between freshwater runoff and sediment transport to the ocean on the adjacent shelf is well documented (Rodolfo 1970; Rice et al. 1976; Brownlie and Taylor 1981; Schwalbach and Gorsline 1987; Stone and Chang 1987; Leithold 1989). Since there was a significant increase in % clay at Station 0 and the annual survey average showed a major peak in 1993, it was concluded that the regional pattern was associated with freshwater runoff during the 1992–1993 El Niño (Seymour et al. 1984, Seymour 1989). Although we speculate that outflow from the Santa Ana River and lower Newport Bay may contribute clay size particles to the shelf, the sampling design does not presently include these potential sources.

Median grain-size was compared between Station 0 and CON from 1985–1994 (Districts 1994). No significant differences in median grain size were determined between these stations, but there were some minor differences in seasonal fluctuation. Greene (1976) reported changes in grain-size composition, especially of the clay fraction between the 1950's and 1973 around and down current from an outfall off Palos Verdes. He also recognized the importance of resuspension of clay and silt-size particles. Based on modeling Farley (1990) estimated that 34% of sewage particles may be deposited within 20 km of the Orange County outfall.

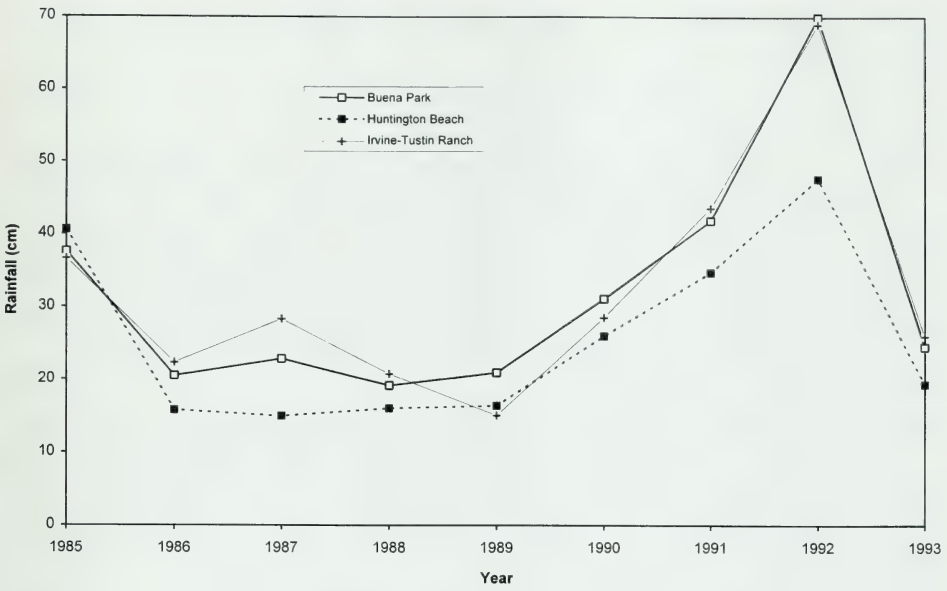

Fig. 6. Rainfall (cm) for three local stations 1985–1993.

Since there was a significant increase in % clay at Station 0 (Fig. 4B) through time, the hypothesis was rejected. The Districts' outfall and operation was associated with local (Station 0) alteration of sediment properties from 1985 through 1993.

The focus of this account has been on the physical properties of local and regional sediments. Moreover, there is evidence to show that some particulate contaminants (Ag, Cd, tPCB) have accumulated in elevated concentrations in sediments at Station 0 compared to other stations (Maurer et al. 1994; Districts 1994; Phillips and Hershelman 1996). However, sediments from the outfall compared to reference stations have produced no statistically significant toxic effects in a large series of sediment bioassays with worms, brittlestars, and amphipods (Districts 1994; Gerlinger et al. 1995; Gerlinger 1995).

In summary, there are several major trends in sediment distribution. First, sediment size was coarser in the western and northwestern portion of the study area becoming finer eastward towards the Newport Canyon. The potential influence of the Santa Ana River and lower Newport Bay may be involved here. Second, sediment size was coarser in shallow water becoming finer in deeper water downslope. This pattern was interrupted around and downslope from the outfall where sediment size increased with increased % of shell hash. Third, there was evidence to support statistically significant alteration of % clay by the discharge. Fourth, the 1993 peak in % clay was for all stations attributed to the 1992–1993 El Niño was associated with heavy rainfall and terrestrial runoff.

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Reproduction and Population Dynamics of a Population of *Grandidierella japonica* (Stephensen) (Crustacea: Amphipoda) in Upper Newport Bay, California

Darrin J. Greenstein and Liesl L. Tiefenthaler

Southern California Coastal Water Research Project,
7171 Fenwick Lane, Westminster, California 92683

Abstract.—Patterns of reproduction, as measured by brood size and abundance, were studied for a population of the amphipod *Grandidierella japonica* (Amphipoda: Gammaridea) in Newport Bay, California during the period of July 1993 to June 1994. Weekly measurements of temperature, salinity and photoperiod were also made at the study site. *G. japonica* reproduced year-round at this site. However, both brood size and abundance declined during the winter months. Large females were found to have both a larger brood size and produced offspring of greater length. Physical factors, such as temperature and photoperiod, appear to play a role in the pattern of reproduction. However, biotic factors, such as food supply and predation, which were not measured in this study, appear to have an effect as well.

Grandidierella japonica (Amphipoda: Gammaridea) is a small (usually <10 mm), tube-dwelling amphipod that was introduced from Japan to California where it was first reported in San Francisco Bay in 1966 (Chapman and Dorman 1975) and in Newport Bay in 1979 (MBC and SCCWRP 1980). It currently occurs in intertidal and sub-tidal sediments of bays and estuaries of California from San Francisco to San Diego (Lamberson et al. 1994).

Little is known about the biology and life history of *Grandidierella japonica.* It inhabits U-shaped tubes in sediments ranging from coarse sand to clay (MBC and SCCWRP 1980). We have successfully cultured *G. japonica* in our laboratory at temperatures ranging from 15 to 23°C and have found the generation time to be about 30 d at 19°C, under laboratory conditions (Nipper et al. 1989). The eggs develop in the marsupium of the female and juveniles are released within 7 to 10 d after the first appearance of the eggs. In the lab, females are known to produce at least one more clutch of eggs (D. Greenstein, unpublished observations). The life span and number of broods of young produced are unknown. Some life history information is available on a related species, *Grandidierella bonnieri,* which inhabits coastal areas of India (Nayar 1956).

We have developed short-term (10 d) and long-term (28 d) sediment toxicity tests using *G. japonica* (Nipper et al. 1989) and the methods for the short-term tests were published by the American Society for Testing and Materials (ASTM 1991). The 28 d test has end points of survival and growth. We have also conducted longer term tests where fecundity has been used as an end point.

For the long-term tests, 3 to 7 d old juveniles are added to the sediment. The juveniles are obtained from gravid females collected in the field and held in separate petri dishes in the laboratory until the young are released. During pre-

vious experiments, females generally released 10 to 40 young (average about 25) (SCCWRP unpublished data). However, during an experiment in March 1992, females released as many as 150 offspring (average about 40). This prompted us to seek additional information on the natural variability of brood size and factors affecting brood size in the wild population of *G. japonica.* Among factors likely to influence fecundity are photoperiod (Segerstråle 1970; DeMarch 1977; Steele et al. 1977; Steele 1981; Williams 1985), temperature (Moore and Francis 1986; Morritt and Stevenson 1993) and biotic factors such as food supply (Wildish 1982).

The objectives of this study were to measure fluctuations in abundance and fecundity in a population of *Grandidierella japonica* in Newport Bay, California and to identify possible relationships between fecundity and environmental characteristics such as temperature, salinity and photoperiod.

Materials and Methods

Grandidierella japonica and water samples were collected between July 1993 and June 1994 from Upper Newport Bay (33°37′N, 117°53′W) on the south shore of Shellmaker Island, west of the Newport Dunes Aquatic Park boat launching ramp. A water sample was collected weekly from the bottom in approximately 1 m of water with a 3 L Van Dorn bottle. Water temperature was recorded and the water sample was taken to the laboratory where salinity was determined from conductivity measurements performed with an Orion 122 Conductivity Meter.

Population density was determined by taking three sediment cores monthly in approximately 0.5 m of water with a 78 mm diameter (48 cm^2) stainless steel hand core. All core samples were taken within 2 h of low tides and were haphazardly distributed along approximately 50 m of shoreline. The cores were packaged separately and taken to the laboratory where they were screened through a 0.3 mm sieve within 24 h. *Grandidierella japonica* were counted and scored by eye as male, ovigerous female, or non-ovigerous female. Any individuals that could not be sexed by eye were scored as juveniles.

In order to obtain gravid females for the fecundity measurements, samples of surface sediments were collected monthly in approximately 0.5 m of water with a shovel and sieved through a 1 mm screen in the field. Material retained on the screen was taken to the laboratory. The first 65 gravid females encountered were removed from the animals collected on the screen. However, fewer than 65 gravid females were collected during some months. Each gravid female was placed in a separate 60 × 15 mm petri dish filled with seawater. The dishes were kept at 20°C and checked daily until all juveniles were released (within 8 d). The offspring were then collected and counted. After releasing offspring, up to 19 females were preserved in alcohol for length measurements and all of the juveniles from up to five of these females were preserved for length measurements.

Amphipod length was measured by projecting a silhouette of their body on a Nikon Shadowgraph at a 10× magnification and tracing a line along the middle of the body that extended from the tip of the rostrum to the end of the telson. These tracings were made onto a clear plastic sheet. The drawings were then retraced on a digitizer board with the digitized values being converted to millimeters, using a computer program written in Basic language.

Descriptive statistics were calculated for all replicate data. Female size, juvenile

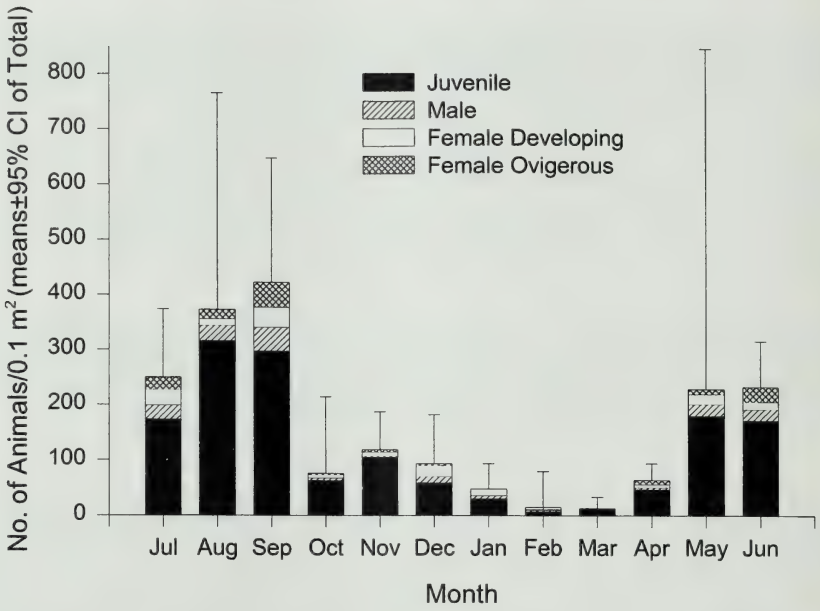

Fig. 1. Number of *Grandidierella japonica* collected in cores per 0.1 m^2 in Upper Newport Bay from July 1993 to June 1994 (N = 3; mean ± 95% C.I. for total number).

size and proportion of each sex class of animals in the cores were tested for temporal variation by analysis of variance (ANOVA) and Student-Newman-Keuls multiple comparison test (Zar 1984). Proportion data were arcsine transformed before testing. Data that failed a test for normality were tested with Kruskal-Wallis ANOVA on ranks and Dunn's multiple comparison test (Zar 1984). The relationship between female length and brood size was tested by linear regression (Zar 1984). The relationships between juvenile length and female length or brood size were tested using Kendall's coefficient of rank correlation (Sokal and Rohlf 1995). Correlations between physical factors and biotic factors were tested by Pearson product moment correlation. Photoperiod data were generate as hours and minutes of daylight by a computer program called Sunny 2000 written by Lou Moccia.

Results

The mean total number of *Grandidierella japonica* in the cores differed by two orders of magnitude during the year (Fig. 1). The variability of the core data was high with the coefficient of variation ranging from 20% to over 100%, but a significant difference between months was detected ($P < 0.05$). The abundance decreased in October and remained low through April. Juveniles were found in the cores for each month and accounted for greater than 50% of the total (Fig. 2). The largest percentage of juveniles was found in November and the lowest in February. However, the difference between these months was not found to be significant ($P > 0.05$). There were significantly more developing females in January than in March. No significant differences between months were detected for males or ovigerous females.

Gravid females were found during all 12 months of the study. However, during

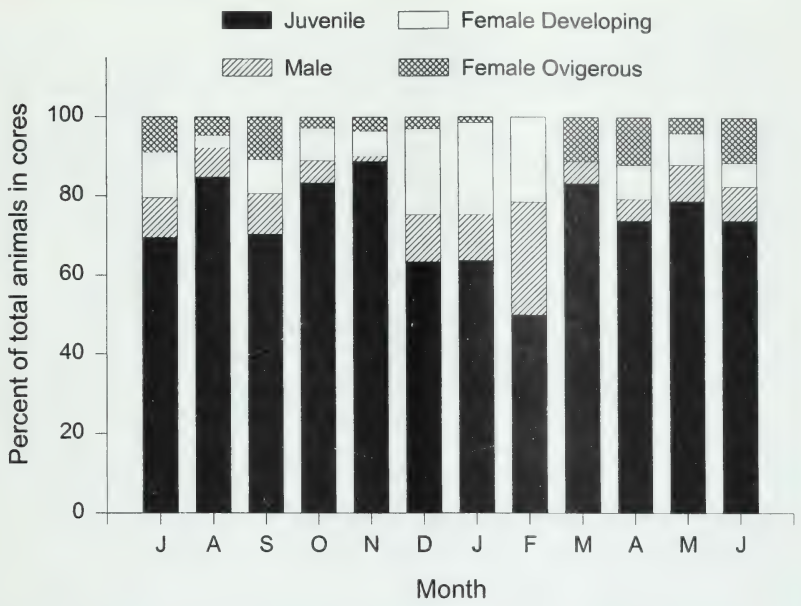

Fig. 2. Percent of each sex category of *Grandidierella japonica* collected in sediment cores.

December through February we were unable to obtain our target of 65 gravid females. The average number of juveniles released per female was lowest from October through January with a low of six in December (Fig. 3). Except for the peak of 29 juveniles released in August, numbers released were similar for February through September (Fig. 3). The brood sizes for October through January were significantly smaller than for all other months except September ($P \leq 0.05$).

The number of young released was significantly related to female length (r =

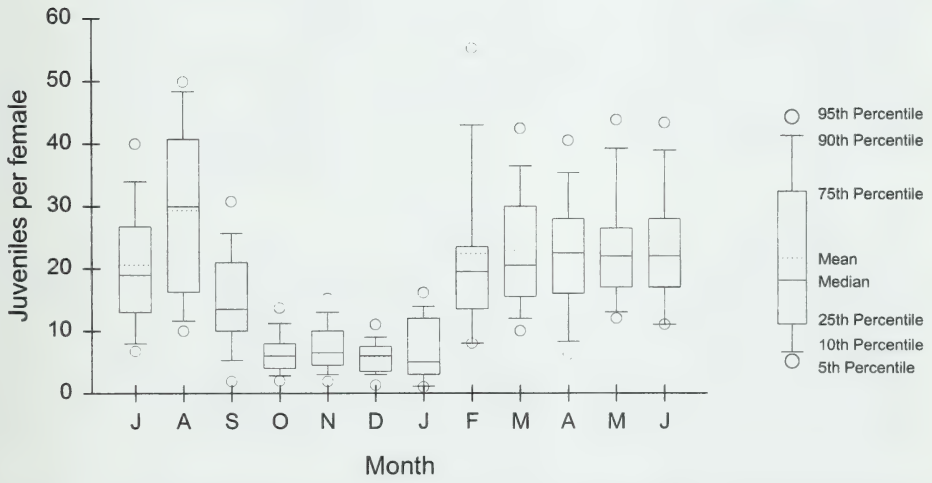

Fig. 3. Number of offspring released by female *Grandidierella japonica* collected in Upper Newport Bay from July 1993 to June 1994 ($16 \leq N \leq 72$ females per month).

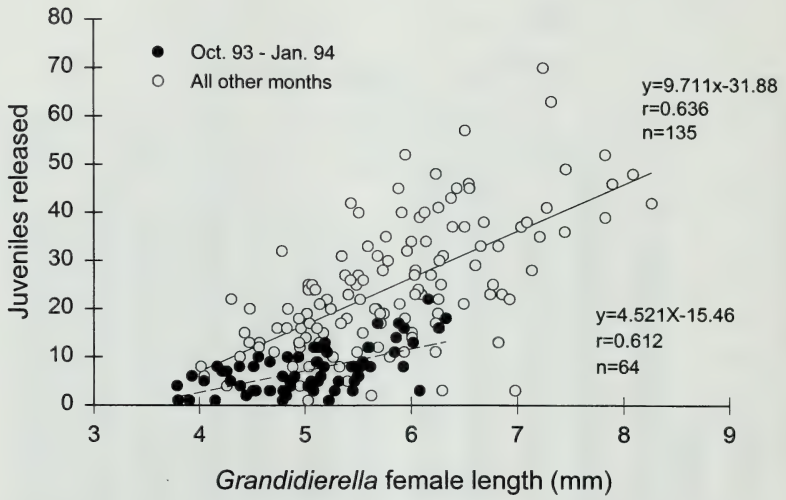

Fig. 4. Number of offspring released versus female length for *Grandidierella japonica* collected in Upper Newport Bay from July 1993 through June 1994.

0.69, $P < 0.05$, N = 199) (Fig. 4), with larger females producing more offspring. The slope was different for females collected from October through January compared to the other months, but larger females still produced larger broods. To minimize the effect of variations in female size, the brood size data were normalized before correlation analysis with the physical parameters. The normalization consisted of using the regression of female length versus brood size for each month to adjust the observed number of offspring per female to the value corresponding to a female of average size (5.58 mm).

The average length of the juveniles released was lowest in July, December, and January (Fig. 5). Animals released in January were significantly smaller than

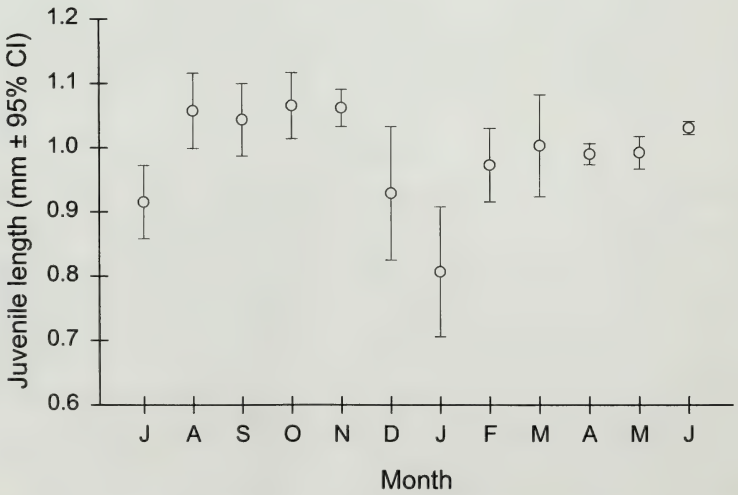

Fig. 5. Length of offspring released from *Grandidierella japonica* females collected in Upper Newport Bay from July 1993 through June 1994 (N = 4–7 females per month; mean ± 95% C.I.).

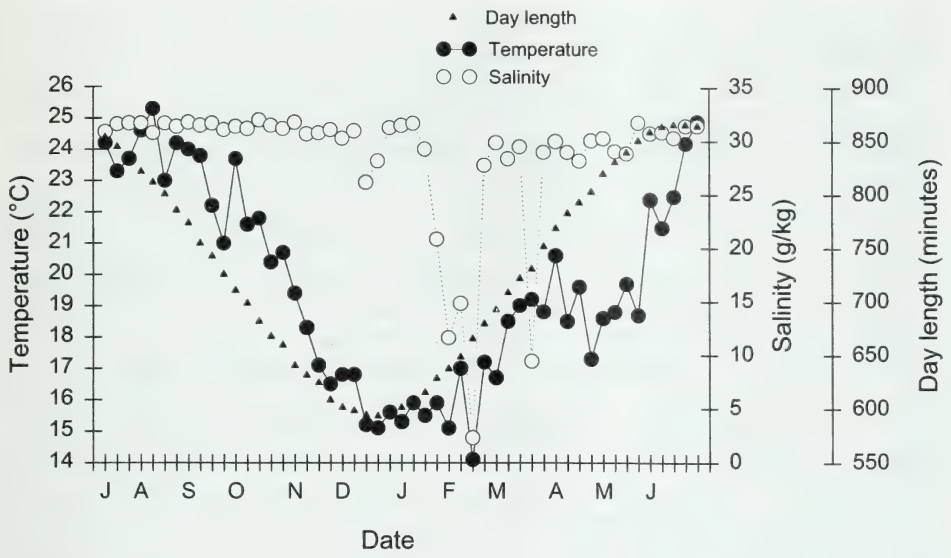

Fig. 6. Weekly bottom water temperature and salinity in Upper Newport Bay, and day length, from July 1993 to June 1994.

animals released in all other months except July ($P < 0.05$). A significant correlation was found between the length of the female and the average length of the offspring produced ($P < 0.05$). However, when offspring length was adjusted for female size (data not shown), the pattern for juvenile size by month remained the same. There was no significant relationship between the brood size and the length of the juveniles.

The bottom water temperature in Upper Newport Bay was highest from June through September and then declined to a low in December (Fig. 6). Day length showed a pattern similar to temperature. Salinity remained fairly constant at about 30 g/kg except for a few declines following periods of rain. A significant correlation was found between temperature and day length ($r = 0.794$, $P < 0.05$). However, mean brood size correlated with day length ($r = 0.756$, $P < 0.05$), but not with temperature or salinity. The total number of animals found in the cores correlated both with day length ($r = 0.815$, $P < 0.05$) and temperature ($r = 0.650$, $P < 0.05$), but not with salinity.

Discussion

The presence of juveniles and gravid females each month during the present study indicates that *Grandidierella japonica* reproduce throughout the year, at this site in Upper Newport Bay. Year-round breeding has been noted in other Gammaridea, especially among those in warm climates (Wildish 1982). If the generation times that we found in the laboratory hold true for the natural habitat, then the population of *G. japonica* may be capable of producing 10–12 generations per year.

The abundance of *Grandidierella japonica* in cores collected from Upper Newport Bay was high throughout the summer, declined in the fall to a low in winter, and recovered the following spring. A similar pattern was observed by MBC and

SCCWRP (1980). In that study, *G. japonica* were collected at most stations in November, December, and July, but were rarely collected in January and March. In our study, juveniles represented greater than 50% of the animals in all months, with their proportion being lowest during December through February, when fecundity was also low. The high variability within each month of the abundance data in the present study suggested that the animals had a patchy distribution. Power analysis on data at the start of the study indicated that about 20 cores per month were necessary to achieve an 80% chance of detecting a 50% change in the population. Unfortunately, time constraints prevented us from collecting and analyzing more than three cores per month. More cores might have allowed us to better distinguish differences amongst the developing and ovigerous female classes.

The annual pattern of decreases in abundance and fecundity in *Grandidierella japonica* parallel decreases of temperature and photoperiod in Upper Newport Bay. Unfortunately, there is no laboratory verification available for how these parameters affect reproduction of *G. japonica.* The initiation of reproduction in the beach flea, *Orchestia gammarellus,* is affected by temperature, but not by changes in photoperiod or salinity (Moore and Francis 1986; Morritt and Stevenson 1993). There is a large body of work indicating that reproduction in various amphipods is affected greatly by photoperiod (Segerstråle 1970; DeMarch 1977; Steele et al. 1977; Steele 1981; Williams 1985). In our study, photoperiod correlated both with fecundity and abundance. The decreases in fecundity and abundance began to occur as photoperiod was reduced, but before the temperature had started to drop. These factors indicate that photoperiod may have an effect on the reproduction of *Grandidierella japonica.*

While the seasonal brood size pattern observed for *Grandidierella japonica* is similar to other species of Gammaridea, the pattern of offspring size is opposite of what is expected. More northern Gammaridea species usually produce smaller clutches during the colder months, but this is associated with an increase in egg size, giving the offspring a better chance of surviving harsh conditions (Van Dolah and Bird 1980; Kolding and Fenchel 1981; Skadsheim 1984). During our study, *G. japonica* had reduced brood sizes in the winter, but this was coupled with a decrease in juvenile size. For the *G. japonica* population that we studied, temperature variations were relatively small and did not correlate with changes in brood size. Temperature may not play as large a role in determining offspring and clutch size for this species as it does for colder climate species.

Though it is possible that temperature and photoperiod could directly affect reproduction of *Grandidierella japonica,* the effect on the availability of food, such as algae, may also be important. The decrease in brood size during the winter, and the decrease in juvenile size in December and January, indicate that less energy was expended on reproduction, perhaps because of reduced food availability. While we have no quantitative data on food supply, it was noted that the cover of algae was lower during the winter months.

Although changes in fecundity should have an effect on population size, changes in mortality rate may have played an important role in affecting this *Grandidierella japonica* population. While the decrease in fecundity was about four-fold, the decrease in abundance was about 10-fold. A reduction in food supplies coupled with lower water temperature and reduced salinity (due to freshwater runoff from storms) could decrease juvenile production and increase adult and

juvenile mortality. The survival of *G. japonica* in the laboratory decreased by more than 10% at a salinity of 10 g/kg during a 10-d test (SCCWRP, unpublished data).

To what degree predation plays a role in controlling the population structure of *G. japonica* is unknown. The abundance of fish in the littoral zone in Newport Bay is quite high from summer through fall (Allen 1982) and many of these fishes prey on amphipods (Horn and Allen 1985). If larger amphipods are selectively removed by predation, then by the end of fall the smaller females, producing fewer offspring, would be left. In the spring, with fewer predators and more abundant food, the females may survive longer and grow larger producing greater brood sizes. Since we did not measure all of the females collected in our study, the data are not sufficient to determine if the average length of the females changes throughout the year.

The seemingly inefficient pattern of both brood size and juvenile size decreasing during the harsher winter months may be explained by a combination of many factors. Brood size and size of the offspring decreased during the winter. Brood size and juvenile size are positively correlated with female length. However, changes in brood size and juvenile size are not entirely accounted for by differences in female length. In explaining changes in brood size and juvenile size, not only factors that affect reproduction must be observed, but also factors that affect female size. Photoperiod may act as a cue to reduce reproduction, but factors such as reduced food supply or predation may cause the average female to be smaller, thus reducing both juvenile production and size.

Learning more about the life history of *Grandidierella japonica* is important, given its use in sediment toxicity tests. Laboratory studies are needed to better define the roles of temperature, food and photoperiod on reproduction. Other species of amphipod are known to change their breeding habits depending on latitude (Wildish 1982). A field study similar to ours on the more northern *G. japonica* population in San Francisco Bay might determine if it behaves in a like manner.

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Williams, K. L. 1970. Insect mimicry. Academic Press, vii + 326 pp.

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COVER: Photo of Spotted Sand Bass by Lara A. Ferry.

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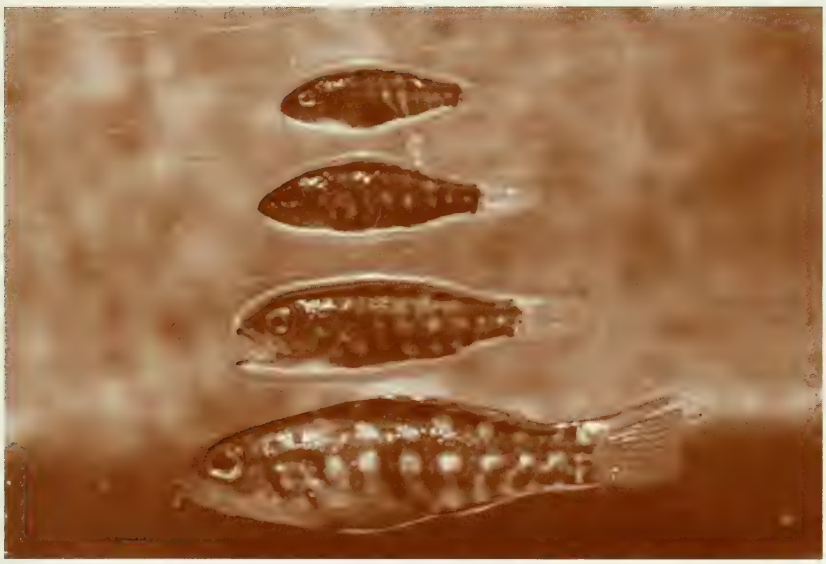

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Estimates of Age, Growth, and Settlement from Otoliths of Young-of-the-Year Kelp Bass (*Paralabrax clathratus*)

Jan F. Cordes[1] and Larry G. Allen

Department of Biology, California State University, Northridge, California 91330

Abstract.—Settled young-of-the-year (YOY) and older juvenile kelp bass (*Paralabrax clathratus*) were collected off the coast of southern California during the summers of 1989 and 1990. Daily rings on the sagittae of settled YOY kelp bass were used to determine age, estimate growth, and construct ring width profiles for each fish. Laboratory-reared larvae revealed that ring deposition began on the third day after hatching, and confirmed the daily periodicity of ring deposition. The combined 1989–90 growth curve could be described as a linear regression with the equation (length (mm)) = 14.67 + 1.69(age(days)) ($r = .96$), resulting in an average daily growth of 0.59 mm/day for the first 90 days of life. Back-calculated spawn dates suggested a possible lunar periodicity around the full moon. Settlement checks and otolith ring widths were used to determine the time of settlement and explore the possibility of delayed settlement in this species. The average age-at-settlement was calculated to be 30 days, with a range of 25–36 days. Only a single case of delayed settlement was evident from the increment-width profiles of 22 fish.

The kelp bass *Paralabrax clathratus* is one of three congeneric species in the family Serranidae found off the coast of southern California. Traditionally a popular sport fish, local southern Californian *P. clathratus* populations fell off dramatically after heavy post-WWII fishing (Young 1963), but ranked second in the Commercial Passenger Fishing Vessels (CPFV) catch of 1992 (Oliphant 1993). The kelp bass is generally believed to be a long-lived, slow-growing species, and may reach an age of over thirty years and sizes up to 680 mm (Young 1963).

Kelp bass are broadcast spawners with widely dispersed larvae (Beckwitt 1983; Waples and Rosenblatt 1987; Walker et al. 1987). However, with the exception of differentiation based on mitochondrial DNA (Graves et al. 1990), the eggs and early larvae of the three local species of *Paralabrax* are largely indistinguishable (Butler et al. 1982), and have traditionally been treated as a single entity in distributional studies (Walker et al. 1987). This has resulted in an unclear picture of the actual abundances and distributions of *P. clathratus* during its planktonic phase. This ambiguity typifies current understanding of kelp bass early life history. Butler et al. (1982) described the developmental stages of the kelp bass from egg to juvenile using specimens reared in the lab and caught in the field, while Carr (1989, 1994) studied the effect of macroalgal assemblages on the recruitment of post-larval kelp bass to the nearshore benthic habitat. Despite these studies,

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[1] Present Address: Department of Fisheries, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia 23062.

however, wide gaps still remain in our knowledge of the period between hatching and settlement, knowledge which is important to the intelligent management of the kelp bass fishery.

Otoliths provide a record of the early life history of individual fish from which information not only on age, but also on temporal distribution of spawning (Middaugh 1981), growth (Geffen 1982; Volk et al. 1984), larval duration and the timing of settlement (Victor 1982; McFarland et al. 1985) can be obtained. Because a number of studies have reported instances of non-daily growth ring deposition (Taubert and Coble 1977; Neilson and Geen 1985; Bailey and Stehr 1988), it is imperative to validate the daily deposition of growth rings for each species studied, and to standardize the treatment of confounding factors such as sub-daily rings (Fowler 1989). The purpose of this study was to use information derived from otoliths to characterize the early life history of the kelp bass. More specifically, the objectives of this project were to: 1) determine the onset of otolith ring deposition and validate its daily periodicity in kelp bass larvae, 2) estimate average daily growth for settled young-of-the-year (YOY) fish caught in the field, 3) back-calculate birth dates and determine temporal spawning patterns with relation to seasonal and lunar periodicity, 4) estimate average age- and length-at-settlement for larvae, and 5) look for any sign of slowed growth (as evidenced by a change in daily ring width) due to delayed settlement.

Methods

Validation of Daily Ring Deposition

In the summer of 1991, a laboratory experiment was conducted to determine the onset and daily periodicity of sagittal ring deposition in kelp bass larvae. Fertilized eggs of known spawn date (from adults spawned in the lab) were hatched and the larvae reared in 70 L seawater tanks under shaded natural lighting and a mean temperature of 19.6°C (range 19.0°C–20.5°C).

Larvae were reared on a diet of rotifers, which were maintained at a mean concentration of 2000–3000 rotifers/L of seawater in the 70 L tanks for the duration of the experiment. A daily sample of ten larvae from a 28 July spawn were collected on days 1, 2, 3, 4, 5, and 9 after hatching and preserved in 70% alcohol. Larvae from an August 8th spawn were kept under identical conditions but left to grow out until after metamorphosis. Because of a mass mortality in the second week, the only sample obtained from this spawn consisted of three fish collected 18 days after hatching. Sagittae from each lab reared larva were extracted and mounted on slides as described under *Otolith Extraction and Preparation.* No further preparation was needed, and the sagittae were viewed under oil immersion at 1000×. Their growth increments were counted and a regression line constructed to test whether there was a significant deviation from the expected age/ring ratio of 1:1.

For the purposes of this study, a daily growth ring (or increment) was defined as one hyaline and one opaque band, and increment widths were measured from the inner edge of one opaque band to the inner edge of the next (Geffen 1982). Daily and subdaily increments were differentiated using the criteria established by Campana (1984).

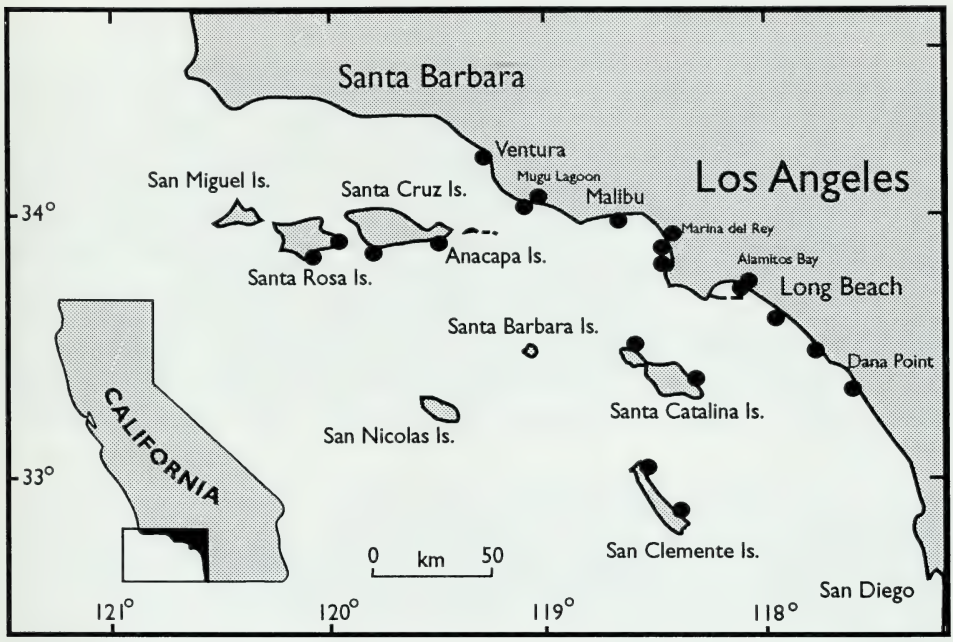

Fig. 1. Map of 19 stations sampled in the Southern California Bight from 1989–90.

Field Collection

Post-settlement kelp bass were collected from drift algae on soft bottom habitats at 19 different stations in the southern California Bight during the summers of 1989–1990 (Fig. 1). At each station, four 5 min benthic tows were taken at 5 m and 10 m depths using beam trawls deployed from two 5.2 m Boston Whalers. The beam trawls had a horizontal opening of 1.6 m and a vertical opening of 0.34 m. The netting of the trawl consisted of 3 mm mesh in the wings and 2 mm knotless mesh in the codends.

In 1989, four mainland and eight island stations were sampled once a month from May through August (Fig. 1). Sampling involved 96 tows per month (except in May, when only 80 tows were made; weather conditions prevented sampling at the Santa Rosa stations), for a total of 386 tows.

In 1990, eleven mainland stations were targeted from July through September (Fig. 1). Of these eleven, nine were sampled at 5 m and 10 m depths, while the shallow embayment stations of Mugu Lagoon and Alamitos Bay were sampled only at the 5 m depth. Due to the silt bottom at these last two stations, it was necessary to sample with a 2 m otter trawl, rather than the beam trawl used for the rest of the study. The same otter trawl was used to sample Marina Del Rey. Sampling in 1990 involved 80 tows per month (except in August, when only 72 tows were conducted because the Marina Del Rey station was omitted), for a total of 232 tows.

Specimens of kelp bass from individual trawl catches were sorted, identified, and frozen on dry ice for transport to the laboratory.

Otolith Extraction and Preparation

In the laboratory, frozen kelp bass were thawed, remeasured to the nearest 0.01 mmSL using digital calipers, and weighed to the nearest 0.1 g wet weight on a Mettler PE3000 precision scale. Using a Wild dissecting microscope with polarizing filters, the three sets of otoliths (sagittae, lapilli, and asterisci) from settled fish were extracted and mounted medial side down on standard microscope slides using a cyanoacrylate (Superglue) medium. Preliminary grinding tests proved the sagitta to be the best otolith for ring visibility, and only these otoliths were used for the remainder of the study. Once mounted, the sagittae were ground and polished on a sagittal plane using 40, 15, 12, 3, and 1 micron 3M lapping films and a special grinding platform devised by Jensen (1990). Each grade of lapping film was used successively in descending numerical order until increment rings could be clearly seen from the focus to the outer edge of the otolith using a light microscope.

Otolith Counts and Increment-Width Measurements

After grinding, all sagittae were viewed under oil at 400× on an Olympus BH2 microscope fitted with an Olympus BH-DA Camera Lucida drawing attachment. This superimposed the image of the otolith over a Jandel 2210 Digitizing Board interfaced with a personal computer. Used in conjunction with the Sigmascan software from Jandel, this system made it possible to simultaneously count the number of rings on each sagitta and determine their widths to the nearest 1 micron. Increment counts and widths were recorded for each sagitta using the digitizing board and a moveable puck by following an eyepiece crosshair superimposed on the otolith's image. Otoliths were not viewed at a higher magnification so that the entire length of the otolith could be surveyed without having to move the microscope stage, which would have interrupted the counts and may have introduced greater errors in accuracy and/or precision. To reduce bias, sagittae were assigned numbers and then counted at random, without knowledge of prior counts. Each sagitta was counted and measured on three separate occasions, and the resulting means were used to back-calculate birth dates, construct growth curves, and compile increment-width profiles for each fish. All sagittae were counted along the best visible axis. The posterior long axis was the most commonly counted axis, since it consistently displayed the clearest growth rings. For standardization, only the otoliths measured along this axis were used to construct increment-width profiles.

A two stage approach was used to determine age-at-settlement for those fish whose otoliths provided increment-width data. First, settlement checks and secondary primordia were visually identified on individual sagittae using the definitions in Victor (1982). Second, increment widths were plotted as a function of age for each individual otolith. Marks were then placed on the resulting increment graphs to indicate the age at which the settlement check occurred for each fish; visible settlement checks could thereby be used to identify any change in increment widths that might be associated with settlement. The resulting graphs were then used to determine the age-at-settlement for each fish.

In the few cases where secondary primordia were found, their day of appearance was noted, since they have been associated with the onset of metamorphosis

and settlement in some flatfish (Koutsikopoulos et al. 1989; Sogard 1991; Toole et al. 1993).

The increment-width graphs were also used to investigate the possibility of delayed settlement. Following Cowen (1991), the graph of each individual fish was scrutinized for any sudden changes in increment widths that would allow the profile to be subdivided into pre-competent, post-competent, and post-settlement stages. Linear regressions were then fitted to the pre- and post-competent stages and their slopes compared by one-way analysis of covariance (ANCOVA) to confirm any significant drop in increment width (and presumably fish growth) that would be indicative of a delayed settlement phase.

An estimate of the length of post-larval fish at settlement was made by averaging the length of those YOY kelp bass determined to have settled just prior to capture.

Statistical Analyses

All descriptive statistics and linear regressions were generated using the Axum software (Trimetrix Inc., Seattle, Washington) package for personal computers. Analyses of variance (ANOVAS) and one-way analyses of covariance (ANCOVAS) were generated using the Complete Statistical System (Statsoft Inc., Tulsa Oklahoma).

Results

Laboratory Validation

Hatchery-reared larvae emerged approximately 36 hours after fertilization, and yolk sac absorption was complete by the third day after hatching. Sagittal ring counts from the 24 collected larvae were plotted against the age (days post-hatching) of the fish, resulting in the linear regression (Age (days)) = 1.82 + 0.97(ring count) ($r = 0.99$, $P < 0.01$) (Fig. 2). Ring deposition began on the third day after hatching and corresponded with yolk sac absorption. Two days were therefore added to all subsequent ring counts used for aging in this study. A one-way analysis of covariance (ANCOVA) indicated no significant difference ($P > 0.05$) between the slope of the regression line (Fig. 2) and the expected slope of 1/1 (one ring per day), thereby validating the daily periodicity of ring deposition in kelp bass larvae. However, because none of the larvae survived to the settlement stage, the continued daily deposition of increment rings after metamorphosis and settlement must be assumed.

Length-Frequency Distributions of Kelp Bass Catches

A total of 111 settled young-of-the-year (YOY) and older juvenile kelp bass were taken during the years 1989–1990. Length-frequency distributions for the two sampling years were highly skewed to the left (Fig. 3). Back-calculated spawn dates suggest that spawning does not begin until May of each year (see results below). Assuming a May first start to the spawning season, and an average daily growth rate of 0.6 mm/day (see results below), one can conservatively assume kelp bass smaller than 25 mmSL in June, 50 mmSL in July, 75 mmSL in August, etc., to be YOY spawned that season. Using these estimates, YOY kelp bass made up 56% (N = 63) of the combined 1989–1990 kelp bass catch, with 27% of these

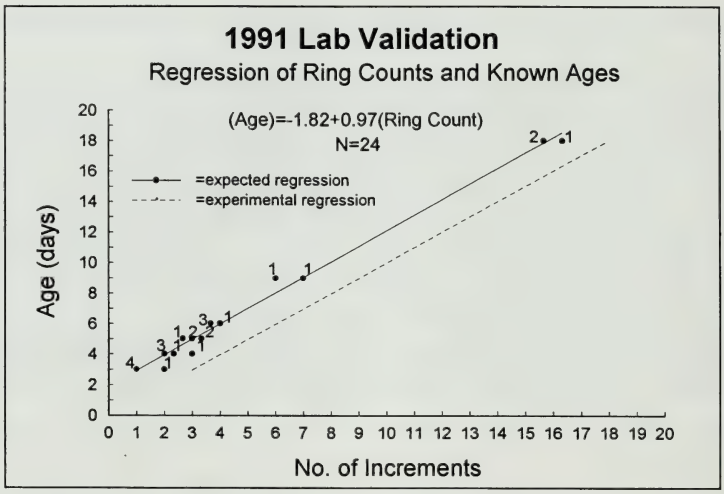

Fig. 2. Results of the 1991 laboratory validation experiment comparing the experimental regression of age based on otolith ring counts (solid line, r = .99) to the expected regression (dashed line). Analysis of covariance (ANCOVA) showed no significant differences between the lines. Values next to data points indicate the number of otoliths which yielded that result.

being newly settled fish ≤10 mmSL which had probably settled less than a week prior to capture. This bias towards smaller fish is probably a result of the sampling gear, which may have been slow enough for larger juvenile and adult fish to avoid. However, the presence of older juvenile fish up to 200 mmSL in the 1989

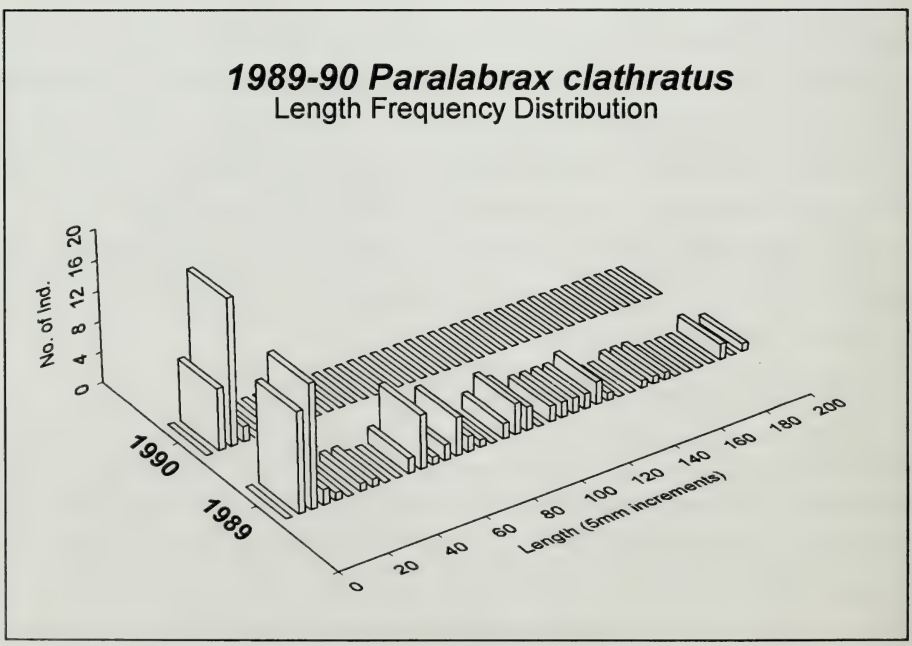

Fig. 3. Length frequencies (grouped in 5 mmSL increments) for all kelp bass sampled in 1989–1990.

sample (Fig. 2) also raises the possibilities that fish settling at many of our stations did not survive to grow larger, or migrated out of these soft bottom areas to more preferred habitats soon after settlement. Comparison of captured fish length-frequency distributions between the two types of nets (otter and beam trawls) used in 1989 showed no differences between the two gear types (two sample t test, $P > 0.2$). In 1989, 83 settled YOY and older juvenile kelp bass were captured ranging in size from 8.5 mm to 200 mmSL (mean = 64.5 ± 52.41 mm SD). Settled YOY fish (≤10 mmSL) made up 41% of the catch, while smaller percentages of one and two-year-old juveniles were clustered around 90 mm and 180 mmSL, respectively (Fig. 3). Newly settled fish made up 38% of the YOY catch.

In 1990, 28 settled YOY kelp bass were captured ranging in size from 9.3 mm to 16.4 mmSL (mean = 11.38 ± 1.8 mm SD). Newly settled fish made up 29% of the total catch, and no older juveniles were captured (Fig. 3).

Age and Growth

Otolith counts taken from settled YOY kelp bass sampled in 1989–1990 were used to determine age-length relationships and estimate growth rates for fish caught in the field. A linear regression of growth was used for samples of both years.

Of the 34 settled YOY kelp bass caught in 1989, 16 had otoliths suitable for counting after preparation. These fish ranged in size from 8.6 mm to 39.5 mmSL, and their length-age relationship was represented by the linear regression (length (mm SL)) = 14.49 + 1.69(age (days)) ($r = .96$, $P < 0.01$). The average daily growth predicted by the model for fish in this size range was 0.59 mm/day.

Of the 28 settled YOY kelp bass caught in 1990, ranging in size from 9.3 mm to 16.4 mmSL, 20 had otoliths suitable for counting after preparation. Their length-age relationship was described by the linear regression (length) = 10.90 + 2.04(age) ($r = .92$, $P < 0.01$), and the average daily growth predicted was 0.49 mm/day.

Results of a one-way ANCOVA indicated no significant difference between the two regressions ($P > 0.05$), allowing the two sample years to be combined. This resulted in the linear length-age regression (length) = 14.67 + 1.69(age) ($r = .96$, $P < 0.01$) and an average daily growth of 0.59 mm/day (Fig. 4).

Back-Calculation of Birth Dates

Using the combined age-length regression from above, the ages of all 62 settled YOY kelp bass sampled in 1989–1990 were estimated and used to back-calculate their birth dates. Graphed by month, the results indicated a pattern typical of a summer spawner (Fig. 5), although apparent spawning peaks should be viewed with caution considering the limited number of specimens. Spawning in 1989 was low in May, increased sharply in June, and then decreased somewhat in July. Because no sampling was done in September of 1989, August spawning could not be characterized. Back-calculated birth dates in 1990 produced a pattern similar to 1989, with spawning beginning in June and rising steadily through July and August.

Back-calculated birth dates were also used to investigate any evidence of a lunar influence on spawning periodicity. Only those fish with otolith counts were used for this analysis (N = 36). A frequency distribution was constructed by

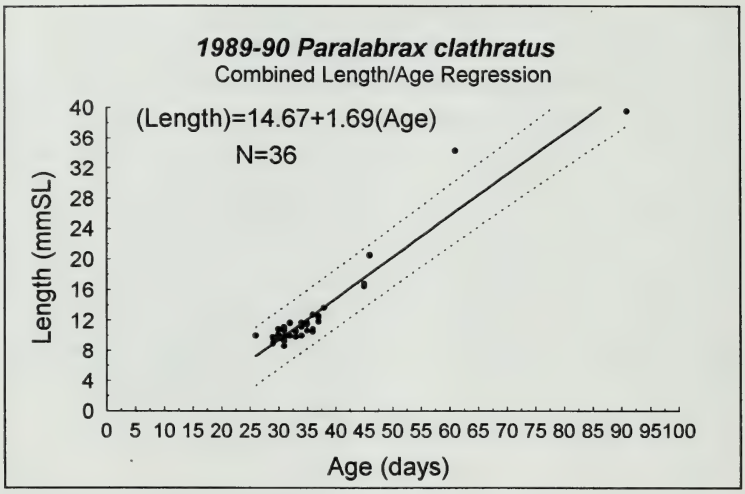

Fig. 4. Combined age-length regression for YOY kelp bass collected during the summers of 1989 and 1990 (r = .92). Dotted lines represent 95% confidence limits.

grouping birth dates in 7-day intervals centered on the four phases of the moon. In 1989 peaks occurred around the full and first quarter moons (Fig. 6A), while peaks in 1990 centered around the full and third quarter moons (Fig. 6B). The greatest number of individuals were spawned in the seven days around the full moon in both 1989 and 1990, with lesser numbers around the first quarter in 1989, and the third quarter in 1990 (Fig. 7). Although these results suggest a

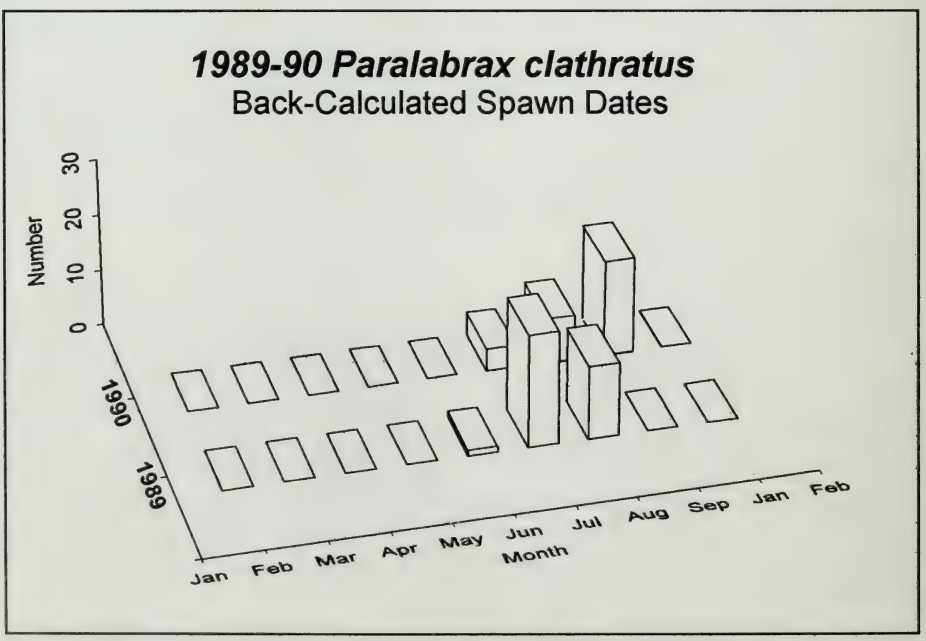

Fig. 5. Back-calculated birth dates by month for YOY kelp bass collected from 1989–1990. Ages were calculated from the combined 1989–1990 age-length regression (Figure 4).

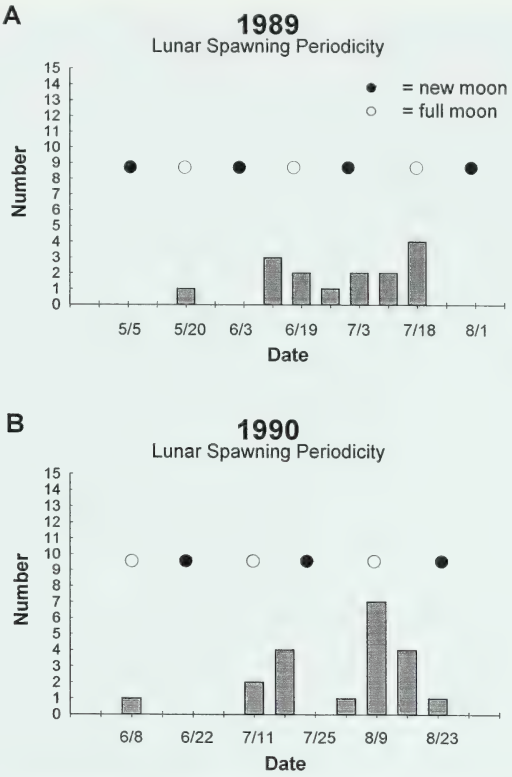

Fig. 6. Relationship between back-calculated birth dates and the lunar cycle for YOY kelp bass collected in 1989 and 1990. (A) 1989, and (B) 1990.

relationship between kelp bass spawning and the lunar cycle, a larger sample size and a time series analysis are needed to bring this relationship into sharper focus.

Timing of Settlement

Graphs of mean daily increment width were constructed for 22 otoliths. Of the 22 otoliths profiled, 12 exhibited settlement checks or secondary primordia which were visible under light microscopy (Fig. 7). The mean age of settlement for these 12 individuals was estimated at 30 days (±2.6 days SD), with a range of 27–36 days. In the ring-width profiles for these 12 fish (see Fig. 8 for examples), the age at which these checks occurred corresponded closely with a peak in increment width the day before settlement, a phenomenon previously linked with the time of settlement in a number of fish species (Victor 1986; Cowen 1991). Using this information, the time of settlement for eight of the remaining ten increment profiles was estimated by determining the day on which this increment width peak occurred. From these data the average age at settlement for 20 of the 22 fish profiled was estimated to be 30 days (±2.7 days SD), with a range of 25–36 days which was virtually identical to the previous estimate for the 12 fish. The two remaining profiles exhibited no distinct increment width jumps, and were omitted from the analysis.

Averaging the mean daily increment widths for all 22 fish indicates that incre-

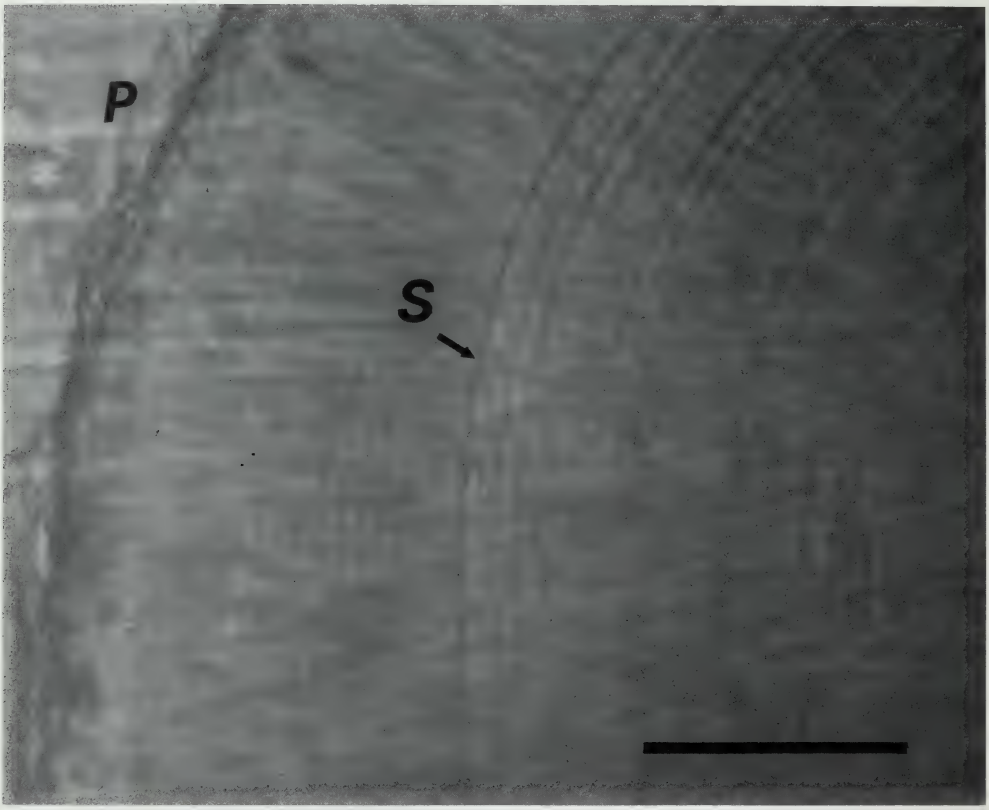

Fig. 7. Photograph of a polished right sagitta from a 40 day old fish (11.80 mm) showing a settlement check. P = posterior edge of otolith, and S = settlement check. Scale bar = 0.1 mm.

ment width increases steadily from approximately 3 microns during the first few days of larval life to 8 microns just prior to an age when settlement occurs (Fig. 9). This suggests that growth rates were accelerating up to the point when larvae became competent to settle. Settlement checks in individual fish were generally evident after increment widths greater than approximately 10 microns were reached. Post-settlement widths leveled off at about 15 microns and remained relatively constant throughout the remaining days of the oldest fish (age = 47 days), suggesting that growth rates were also constant and no longer accelerating as they were in the larval phase.

Qualitative examination of the increment width profiles revealed four fish exhibiting patterns characteristic of delayed settlement (Fig. 10). The boundary between the pre- and post-competent stages was identified as a peak and subsequent decrease in increment width occurring some time before settlement (Cowen 1991). These competency peaks for the four fish suspected of delayed settlement corresponded with the earliest ages-at-settlement reported above, while the actual settlement age for these same fish fell, predictably, as the high end of the range.

Comparison of the pre- and post-competent regressions for each profile by one-way ANCOVA revealed significant differences ($P < 0.05$) between the slopes in only one of the four fish tested (Fig. 10D). These results suggest that these four

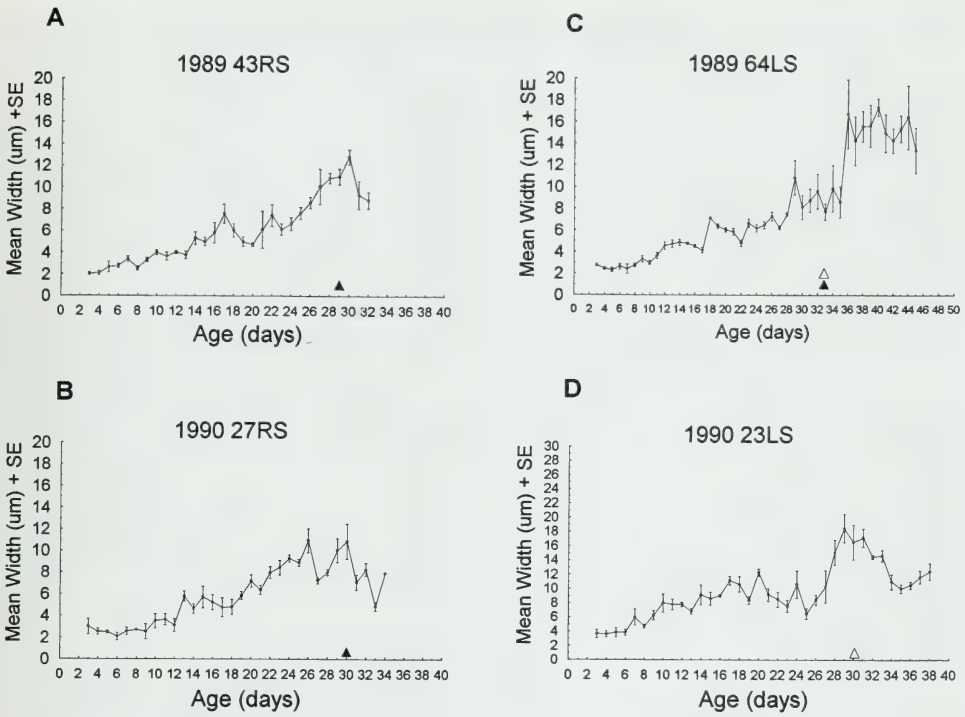

Fig. 8. Representative graphs showing the correspondence of settlement checks (closed triangles) and secondary primordia (open triangles) with an increase in daily increment width. (A) 1989 43rs = right sagitta from the forty-third YOY kelp bass collected in 1989, (B) left sagitta from the sixty-fourth YOY kelp bass from 1989, (C) left sagitta from the twenty-third YOY kelp bass collected in 1990, (D) right sagitta from the twenty-seventh YOY kelp bass collected in 1990. Bars represent ± one standard error (SD) around the mean.

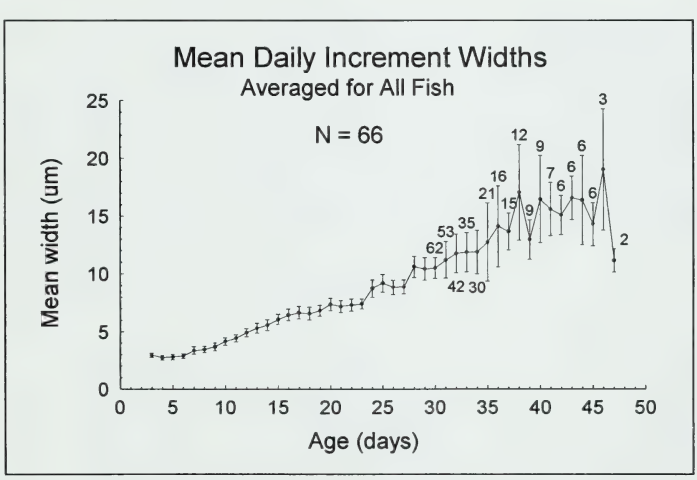

Fig. 9. Mean daily increment widths for 1989–1990 YOY kelp bass over the first 48 days of life. Three readings were averaged for each of 22 fish for a total N = 66. Numbers above and below line indicate decreasing sample sizes as younger fish dropped out of the calculations. Bars represent ± one standard error around the mean.

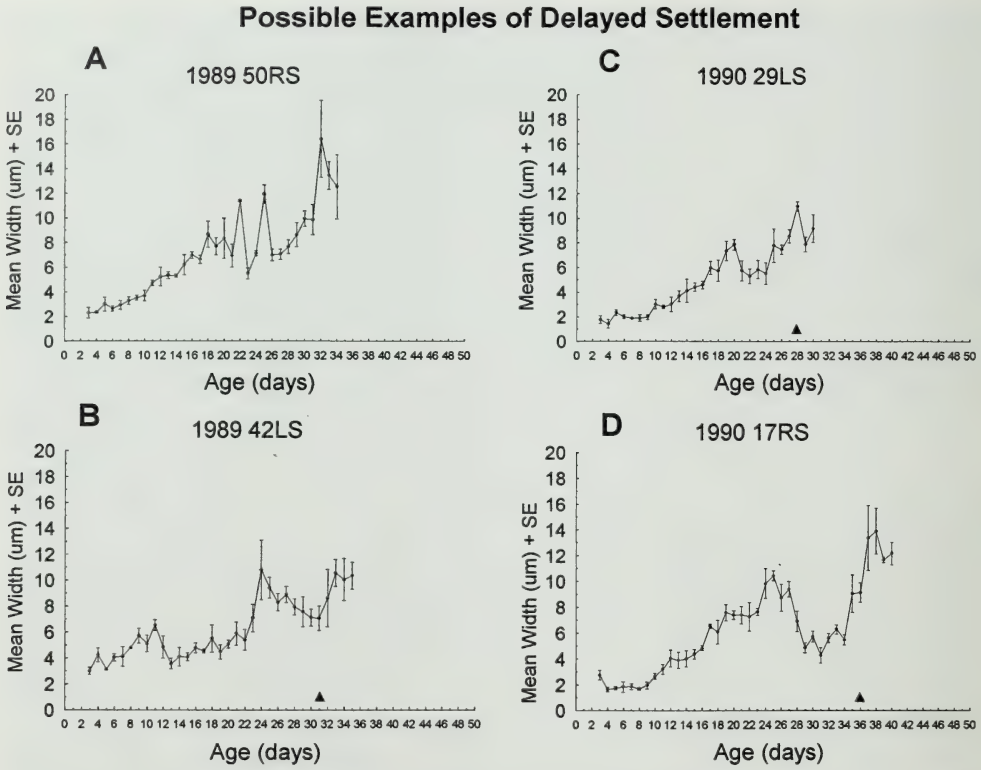

Fig. 10. Examples of increment width profiles from four YOY kelp bass which may have undergone delayed settlement. (A) 1989 50rs = right sagitta from the fiftieth YOY kelp bass collected in 1989, (B) left sagitta from the forty-second YOY kelp bass collected in 1989, (C) left sagitta from the twenty-ninth YOY kelp bass collected in 1990, (D) right sagitta from the seventeenth fish collected in 1990. Settlement check = closed triangles. Bars represent ± one standard error around the mean.

fish may have undergone a slow-growth phase which delayed their time of settlement, although quantitative confirmation was difficult to obtain.

The smallest settled YOY kelp bass captured was 8.59 mmSL and determined to be 31 days old from otolith counts. To determine the average size at settlement, fish between the ages of 25–36 days (the range of settlement ages determined earlier) were presumed to have been captured immediately after settlement. These fish ranged in size from 8.59–12.71 mmSL and averaged 10.3 mmSL.

Discussion

Reproduction and Spawning

Data from back-calculated spawn dates (Fig. 5) show the pattern of a summer spawner, although the time of peak spawning activity could not be determined due to logistical limits on the duration of sampling each summer. Studies characterizing the spawning season of kelp bass on the basis of seasonal gonad maturation (Smith and Young 1966) and the presence of larvae from the three species of *Paralabrax* in the ichthyoplankton from the southern Californian Bight (Walker et al. 1987), indicate that spawning activity begins in May, peaks in August or September, and ceases by October. Recent work by Oda et al. (1993) suggests

that kelp bass are late afternoon spawners, and may be capable of daily spawning during their reproductive season.

Although the reproductive behavior of kelp bass has not been thoroughly studied, adults of the species are known to form offshore spawning aggregations (Feder et al. 1974). Johannes (1978) proposed that similar strategies in tropical fishes may serve the dual purpose of enhancing larval dispersion while avoiding nearshore benthic reef predators which might feed on eggs and small larvae. One danger incurred by offshore spawning is the possibility of larvae being swept out to sea and lost. Parrish et al. (1981) investigated the effects of the California Current and upwelling events in central California on the distribution patterns of marine fishes. They found that spawning activities in a large number of species coincided with the net onshore flow characteristic of central California waters in the late winter and early spring. These onshore currents would tend to transport the eggs and larvae of pelagic spawners back toward shallower waters. Internal waves may play a similar role in the onshore transport of fish larvae in the neuston (Shanks 1988). Transforming larvae of California halibut, *Paralichthys californicus,* have been shown to migrate from bottom to surface waters at night (Kramer 1990), and may be utilizing internal waves to reach nearshore nursery grounds (Moser and Watson 1990). Recovery of drift bottles released less than twenty miles offshore in the southern California Bight is greatest from March through October (Schwartzlose 1963), indicating that onshore flow is high during the summer months when kelp bass spawning occurs.

Back-calculated spawn dates also suggested a relationship between spawning activity in kelp bass and the lunar cycle (Figs. 6–7). Data from both years showed that spawning peaks coincided with the full moon. Spawning around the full moon has been widely documented for many tropical fish families, including two species of epinepheline serranids (Johannes 1978). Less is known regarding temperate serranids, but at least one species of sea bass from the mid-Atlantic Bight, the gag (*Mycteroperca microlepis*), has been shown to spawn around the full and new moons (Keener et al. 1988). More important than the lunar cycle itself, however, may be its relationship to the tidal flux. Middaugh (1981) found that the Atlantic silverside, *Menidia menidia,* spawned during daytime flood tides on the full and new moons. The author suggested that spawning during incoming high tides may increase fertilization success. Conversely, some tropical species spawn in conjunction with out-going spring (new and full moon) tides to facilitate offshore transport and distribution of pelagic eggs (Johannes 1978). It is not known whether kelp bass spawning is correlated with spring or ebb tides, but the association between spawning and the full moon, in conjunction with the one month larval period, suggest that lunar and/or tidal cycles may play an important role in both the time of spawning and settlement in this species.

Validation of Increment Initiation and Daily Periodicity

The chronological sequence from fertilization to yolk sac absorption reported in the hatchery validation experiment are consistent with that found by Butler et al. (1982) for laboratory-reared kelp bass larvae. In addition, results from the validation study determined that initial sagittal ring deposition occurred on the third day after hatching, and corresponded with yolk sac absorption. This correspondence is common in marine fishes (Brothers et al. 1976; Victor 1982; Geffen

1982; Tzeng and Yu 1988), although onset of ring deposition has also been shown to begin prior to hatching (Radtke and Dean 1982) and at hatching (Brothers et al. 1976; Bolz and Lough 1988). Although ring deposition was found to be daily during the larval period, the failure to raise kelp bass past the settlement stage left open the question of continued daily deposition in juveniles. There is, however, little reason to believe that daily deposition would not continue past the larval stage.

Daily Growth Estimates

The use of otolith increments in the construction of growth curves assumes that daily deposition of rings is not interrupted by environmental or physiological factors. Some studies have shown non-daily ring formation under conditions of starvation (Bailey and Stehr 1988), elevated feeding (Neilson and Geen 1985), and abnormal photoperiod (Taubert and Coble 1977) and temperature regimes (Neilson and Geen 1985). Other studies on a variety of species, however, have shown no disruption of daily periodicity under varying conditions of these same factors (Maillet and Checkley 1990; Campana and Neilson 1982, 1985), although increment quality and width were often affected. The most serious challenge to the concept that daily growth rings are an accurate index of age comes from a study on larval herring, *Clupea harengus,* which found increment deposition to be less than daily in larvae exhibiting suboptimal growth rates (Geffen 1982). Despite these very real concerns, however, there is little reason to doubt the daily formation of increments in fish exhibiting adequate growth rates (see Campana and Neilson 1985 for review).

The estimated average daily growth rate from the combined 1989–1990 data presented here was 0.56 mm/day for fish less than 90 days old. Daily growth rates reported for other temperate eastern Pacific fishes range from 0.20–0.23 mm/day for settled YOY white seabass, *Atractoscion nobilis* (Franklin 1991), to 0.76–1.11 mm/day for settled YOY California halibut, *Paralichthys californicus* (Jensen 1990). Due to the limited age range of YOY kelp bass used to construct the growth curves in the present study, a linear regression was deemed adequate to describe the relationship between growth and age. It is assumed that this line would begin to flatten out as growth approached an asymptote during the late juvenile/adult stage, thus more closely resembling the von Bertalanffy growth model more commonly employed in growth studies. Increment analysis showed that ring width increased steadily until the time of settlement, after which point rings became more irregular and no longer exhibit a net increase in width (Fig. 10). Assuming a constant positive correlation with fish growth, this would result in an age-length regression that would appear exponential during the larval phase, linear for the early juvenile stage, and then begin to flatten out as the older fish grew more slowly.

Age at Settlement

Settlement checks are a common means used to determine the duration of the planktonic phase of fish species with pelagic larvae (Campana and Neilson 1985; Victor 1986, 1991; Wellington and Victor 1989). Such checks are presumed to be a result of stress associated with a transition from a pelagic to a demersal habitat, although direct evidence of this is scarce (Campana and Neilson 1985).

Formation of a settlement check has been validated, however, for at least one family of fishes, the labrids (Victor 1982; Cowen 1991). As mentioned before, changes in physiological and environmental conditions which may occur at metamorphosis and settlement have been associated with a change in otolith increment width. Settlement checks have also been shown to be associated with such changes in increment width (Fowler 1989, Cowen 1991), allowing for a way to double check the validity of visually identified settlement marks.

The average age-at-settlement reported in this study is comparable with the average settlement age of 35 days for white seabass, *Atractoscion nobilis* (Franklin 1991), and 28 days for California halibut, *Paralichthys californicus* (Jensen 1990). There is often, however, a large range of variation among species, even within families. Victor (1986), for example, reported a range of mean ages from 15 to 121 days among one hundred species of labrids, while Brothers et al. (1983) found a range of means between 19 and 74 days among twelve families of fishes from the Great Barrier Reef.

The average length at settlement of kelp bass of 10.3 mmSL reported here is somewhat overestimated, because the fish used in the calculations were assumed to have settled just prior to capture. The two events may actually have been separated by several days, thus adding any fish growth during these intervening days to the estimate. The actual average may be closer to 9 mmSL, a value somewhat smaller than that of 11 mmSL found by Butler et al. (1982) for metamorphosing laboratory-reared kelp bass larvae.

Whether the larvae of fishes are capable of playing an active role in determining where and when they settle out of the water column has received much attention in recent years. Boehlert and Mundy (1988) list studies on a variety of fish taxa which show that the immigration of larvae into estuarine nursery grounds involves an active behavioral process. Carr (1994), however, showed that the correlation between settlement of kelp bass larvae and the presence of algae was probably passive in nature. Regardless, the ability to delay settlement until a suitable habitat is reached, either by active or passive means, could prove valuable in areas where such habitat is scarce or patchy in distribution. The ability of larvae to delay metamorphosis and settlement, especially in the absence of suitable settlement cues, has been documented for a variety of invertebrate taxa (see Jackson and Strathmann 1981 for review). This delay is often correlated with a marked decrease in growth, presumably due to the reduced survival of larger larvae in the plankton (Scheltema 1971). Precompetency is the term used to describe the period of development up to the point when the larvae is physiologically able to settle, while postcompetency describes the period of reduced growth between competency and settlement (Jackson and Strathmann 1981). Evidence for similar mechanisms in teleosts have been reported in at least two cases (Victor 1986; Cowen 1991). Through field collections and subsequent otolith analysis, Victor (1986) showed that some post-larval bluehead wrasse, *Thalassoma bifasciatum,* went through a slow growth phase and concomitant decrease in increment width prior to settlement. His results indicated that fish exhibiting a longer larval stage grew more slowly just prior to settlement. Cowen (1991) reported similar results for the California sheephead, *Semicossyphus pulcher,* in which time of settlement was more closely correlated to fish length than age. Species in both studies exhibited a wide range of settlement ages (38–78 days and 37–78 days, respectively) com-

pared to that reported here for YOY kelp bass (25–36 days). In view of this small range of values, it is not surprising that relatively few cases of delayed settlement were identified. Only four possible examples were found in the increment-width profiles of 22 fish, as opposed to 10 out of 11 cases found by Cowen (1991). This suggests that there may be some physiological inflexibility in the duration of the larval phase in kelp bass, although these results must be viewed with caution due to the small sample size.

The results of this study help to characterize the early life history of the kelp bass and the environmental factors that may play a role in determining the abundance and distribution of YOY that will eventually find their way into adult stock populations. The effects of lunar phase and tide on spawning and settlement, the limiting effect of larval availability, and the importance of various environmental cues in the settlement of recruiting larvae, are all areas ripe for future research. Such research is crucial if the recreational fishery for this popular sport fish is to be properly managed.

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The Butterfly Fauna of Two Adjacent Plant Communities in the Sierra Nevada Foothills of Mariposa County, California

Oakley Shields

6506 Jerseydale Road, Mariposa, California 95338

Abstract.—A butterfly fauna encompassing two plant communities in the Sierra Nevada foothills was surveyed and was found to contain 59 resident and 35 non-resident species. 63% of the residents but just 3% of the non-residents are univoltine, and only 44% of the resident species are shared by both plant communities. Dispersal between them by residents normally found in only one of the plant communities rarely occurs. Information on climate, relative abundance, flight season, dispersal, behavior, and bionomics are presented. Based upon paleobotanic inferences, butterfly species endemic to the Foothill Woodland are pre-Pleistocene, whereas the Yellow Pine Forest endemic subspecies are post-Pleistocene (Holocene).

Efforts to identify butterfly indicator species for the various life zones of California have achieved only limited success (cf. Grinnell and Grinnell 1907; Garth and Tilden 1963; MacNeill 1964; Shapiro et al. 1979), although identification of indicator taxa that are endemic to, and thus diagnostic of, a particular plant community that is floristically defined appears more promising. For example, Stone and Smith (1990) found that various *Hemileuca* Walker (Saturniidae) taxa often utilize larval foodplants that are dominant or abundant only within a particular plant community in southwestern North America. In recent years, a spate of butterfly faunal surveys has appeared for various areas within California, but these frequently encompass more than one plant community and de-emphasize a community approach to species distributions. Determination of butterfly indicator species for particular plant communities requires that these communities be more selectively surveyed.

Botanists have already laid the groundwork for California's many different plant communities, each of which is characterized by certain key indicator species (cf. Munz and Keck 1949, 1965; Barbour and Major 1990). To date, however, only the butterfly fauna of the Foothill Woodland plant community in central California has been adequately surveyed in a similar manner (Shields 1986).

Butterflies are primarily dependent upon angiosperms for their larval foodplants and adult nectar sources, and a given plant community is largely controlled by climate, being confined as an adaptive and cohesive unit to a particular climatic zone. Crowe (1965) has demonstrated that certain climatic zone adaptations also exist for *Coenonympha* Hübner (Satyridae) and *Callipsyche* Scudder (Lycaenidae) in Oregon. A high fidelity between butterfly indicator species and the plant community they inhabit is expected due to hostplant restriction there and/or a narrow range of temperature and moisture requirements (see Tilden 1959) to which the indicator species are physiologically adapted. Non-indicator butterfly species, in

contrast, are not so restricted by habitat and climate and regularly occur in more than one plant community, be they non-residents or residents, due to their superior vagility compared with plants and thus do not constitute a butterfly community corresponding to its plant community. Though climatic fluctuations can alter the species composition and distribution of plant communities to some degree (see Shapiro et al. 1979), the persistence of many identifiable plant communities in California argues against any wholesale restructuring during the past 8000 years (see Van Devender and Spaulding 1979; Van Devender et al. 1987). Identifying endemic butterfly species that are indicators of a particular plant community is important to do since this butterfly/plant association likely evolved over similar intervals of geologic time, thus indicating their relative age (cf. Janzen 1968; Shields 1986; Farrell et al. 1992), This idea is quite different from maintaining that entire communities persist and migrate as units through Neogene time.

An ecological survey of the butterfly fauna within two adjacent Sierran foothill plant communities is presented here (see Fig. 1). Special attention is given to distinguishing resident from non-resident species, along with selective aspects of abundance, flight period, brood number, behavior, bionomics and dispersal. Several butterfly indicator taxa (ecotypes) are identified as endemic to the Yellow Pine Forest plant community from the completed analysis and will be discussed.

Methods

A survey of the butterfly fauna was conducted for 28 years between 1961 and 1995 in the Yellow Pine Forest (YPF) plant community and for 17 years between 1970 and 1989 in the Foothill Woodland (FW) plant community (see Fig. 1 and Plant Communities below). At Jerseydale, Mariposa Co., California, casual sampling at irregular intervals was done on 458 days (January–December) in 1961–63, 1965–66, 1970–74, 1976–77, and 1980–95. The summits of Footman Ridge (and sometimes Portuguese Ridge) were visited on 54 days (April–December) in 1971–74, 1976–77, 1980–87, and 1989, and Skelton Canyon on 67 days (January–September, December) in 1970–74, 1976–77, and 1980–89. Resident species were defined as those indigenous to the study area, i.e. breeding and overwintering there, with the first (or only) brood freshly emerging in the habitat the following season. Non-resident species represent migrators or other dispersers that most often did not overwinter, casual or weedy species from nearby or more distant locations, and those hilltopping taxa that were not found at lower elevations within the study area. The flight period of a species was determined from all the dates it was collected or observed during the entire survey, and relative abundance was subjectively assessed from the numbers encountered on those dates. The number of broods for the resident species was checked against Shields (1986) and Scott (1986), and the ecological terminology follows Lincoln et al. (1982). The nomenclature largely follows Miller and Brown (1981), but with a few cited changes by other authors and my personal opinion in the case of some generic assignments.

Habitat

Habitat Description

Most of the Jerseydale valley and forest soils are granitic, gabbro, and quartz diorite in composition, with large granitic boulders and slabs frequently exposed. Footman Ridge is largely comprised of slate metamorphic rocks and soils. Skelton

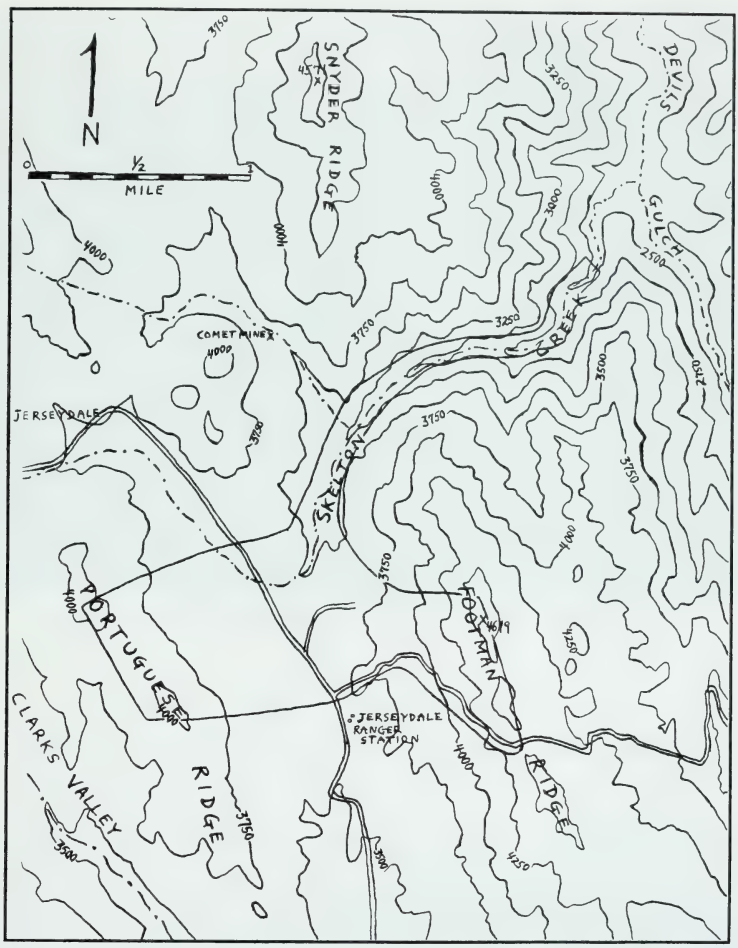

Fig. 1. Topographic map of the study area at Jerseydale, Mariposa County, California. The survey is outlined as the Y-shaped area from Portuguese Ridge to Footman Ridge and Skelton Canyon. Elevation contours are in feet.

Canyon is steep-walled and rockier and consists mainly of various metamorphics including metagabbro, amphibolite, metavolcanics, slate, and greenstone units. The marine metamorphics (Paleozoic) and igneous granites (Mesozoic) form a contact zone mixture near the very top of the canyon. The entire study area is unglaciated.

The forested and riparian habitats at Jerseydale are mostly in their natural state (see Fig. 2), although some timber harvesting occurred in the past. Other disturbances include old logging roads, cattle grazing and several stock pond dams in the Iris-Buttercup meadows, and some disturbed, weedy places especially around habitation. Footman Ridge (see Fig. 3) is relatively undisturbed except for an access road and an old lightning burn with secondary growth. Skelton Canyon is essentially pristine habitat (see Fig. 4) except for a steep jeep road, horse trail, and several abandoned mines.

Fig. 2. Meadow, riparian, and Yellow Pine Forest habitat at Jerseydale.

Fig. 3. The north end of Footman Ridge, viewed from Skelton Canyon.

Fig. 4. Foothill Woodland habitat in Skelton Canyon (foreground).

Plant Communities

The Jerseydale area and the west slope of Footman Ridge are occupied by a species-rich Yellow Pine Forest plant community. The forest indicator trees present (see Munz and Keck 1965) are Ponderosa Pine *(Pinus ponderosa)* (predominant), Sugar Pine *(P. lambertiana),* White Fir *(Abies concolor),* Incense Cedar *(Calocedrus decurrens),* and California Black Oak *(Quercus kelloggii),* and indicator shrubs include Sierra Gooseberry *(Ribes roezlii),* Bear Clover *(Chamaebatia foliolosa),* Mariposa Manzanita *(Arctostaphylos mariposa),* and Deer Brush *(Ceanothus integerrimus).* The warm, southeast-facing slopes of Skelton Canyon, in contrast, are occupied by an ascending Foothill Woodland plant community. Indicator trees present here are Digger Pine *(Pinus sabiniana),* Canyon Oak *(Quercus chrysolepis),* and Buckeye *(Aesculus californica),* and indicator shrubs include Buck Brush *(Ceanothus cuneatus),* Yerba Santa *(Eriodictyon californicum)* and Redbud *(Cercis occidentalis),* with some chaparral community elements present such as Chamise *(Adenostoma fasciculatum)* and Mountain Mahogany *(Cercocarpus betuloides).* Along the northwest-facing slope, upper portion, and mouth of Skelton Canyon, the FW and YPF plant communities intermix in an ecotone, while along the northern slopes and summit of Footman Ridge, the two communities remain distinct but interdigitate as a patch-work of "islands".

Climate

Summers at Jerseydale are generally warm, with the greatest evaporation occurring in May to October; diurnal and seasonal temperature fluctuations are relatively wide, and winds are usually light to moderate (Gilbert and Peterson 1966). The driest months are May to September, and the wettest months are November to March. Jerseydale's seasonal precipitation falls primarily as rain, which always

Table 1. The 1971 to 1995 precipitation totals (July 1–June 30) for Jerseydale Ranger Station, 1113 m, Mariposa County, California. The 25-year average is 1.07 m (42.15 in).

Year	Meters	Year	Meters
1970–71	.79	1983–84	1.07
1971–72	.57	1984–85	.74
1972–73	1.08	1985–86	1.52
1973–74	1.02	1986–87	.61
1974–75	1.19	1987–88	.67
1975–76	.48	1988–89	.72
1976–77	.42	1989–90	.80
1977–78	1.97	1990–91	.76
1978–79	1.15	1991–92	.87
1979–80	1.35	1992–93	1.65
1980–81	.70	1993–94	.70
1981–82	1.82	1994–95	1.97
1982–83	2.13		

exceeded the snowfall's total water content during the years 1980–95. The 15 year average winter snowfall depth from 1980–81 to 1994–95 was 0.64 m, ranging from a low of 0.12 m in 1983–84 to 1.74 m in 1990–91. The earliest snows usually arrive in mid November, with the latest snows in late March (late April in 1994). Decembers vary from comparatively mild and dry to harsh, with strong winds, frosts, hard freezes, and heavy snowfall. Yearly precipitation totals are shown in Table 1. The climate for Skelton Canyon was not monitored, but it is expected to have less annual precipitation, a longer growing season, more frost-free days, fewer snows, and higher average temperatures than Jerseydale (see Munz and Keck 1949).

Some studies indicate that drought can have a severe effect on butterfly numbers, even leading to local extinction in some highly variable populations, while warm, dry summers, or wet conditions early in the previous year, tend to increase their numbers (cf. Ehrlich and Murphy 1981; Pollard 1988; Pollard and Yates 1993). During the severe drought years at Jerseydale (1972, 1976–77, 1987), butterfly species indeed were generally in very low numbers, with few species becoming common except for *P. napi, C. tullia, N. californica,* and *L. arota* (see Table 2). Unusually high precipitation occurred from October to April during the 1981–82 and 1982–83 seasons, with late snows in 1981–82 and heavy rains with little snow in 1982–83. 1983 was a high abundance year for *N. menapia, P. napi, E. hyantis, H. grunus, M. nelsoni,* and *G. piasus,* and also produced several nymphalid melanics. Following unusually cold weather in late December of 1990 and 1992 (10 day runs of temperatures below 0°C at night), and night-time temperatures approaching −18°C on February 5–7, 1989 and December 28, 1990, butterfly species diversity plummeted from 1989 to 1993, with only partial recovery in 1994 and 1995 and regaining normalcy in 1996.

Results

Resident vs. Non-Resident Species

The survey area produced 59 resident and 35 non-resident species (see Tables 2 and 3) for a total of 94 species (37% non-resident). Of the 59 resident species,

37 (63%) are univoltines (=one generation per year), the remaining third being bivoltines or multivoltines that overwinter as pupae or, infrequently, as adults. The largest segment of residents are lycaenids (37%), while 54% of the non-residents are nymphalids and hesperiids, only 17% being lycaenids. Of the non-residents, *Z. eurydice, P. pulchella, A. milberti, P. faunus, P. satyrus, E. brizo, E. tristis,* and *H. columbia* represent occasional dispersers from relatively nearby locations where they are permanent residents. The remaining 25 non-residents are primarily non-diapausing multivoltines that are known to migrate, occasionally migrate, or frequently disperse well beyond their normal ranges. Of these, only *C. eurytheme, D. plexippus,* the four *Vanessa, J. coenia,* and *I. acmon* regularly breed and recolonize within the survey area, though *P. protodice* and *H. ericetorum* do so occasionally. *B. philenor, Z. cesonia, P. sennae, D. gilippus, E. claudia, L. bachmanii,* and *P. leo* (see Table 3) commonly co-occur in SE Arizona (Bailowitz and Brock 1991) and likely represent long-distance migration dispersal. Excluding these stronger migrants and short-distance dispersers, the remaining 14 non-resident species are oligophagous or polyphagous and disperse upslope from the San Joaquin Valley as regular or occasional species and invaders.

The results that follow will be primarily concerned with the resident species.

Abundance

Occasional population outbreaks were noted for *N. menapia, N. californica, V. cardui, M. nelsoni, S. californica, S. auretorum, I. icarioides,* and *H. ericetorum.* High abundance years for other species included *C. sthenele* (1981), *C. tullia* (1965, 1966), *D. plexippus* (1987–88, 1991), *S. callippe* (1974), *S. hydaspe* (1974, 1976), *N. antiopa* (1970), *L. arota* (1972), *H. grunus* (1983), *I. eryphon* (1974) and *H. harpalus* (1985, 1989). Species generally displaying little fluctuation in abundance from year to year were *P. multicaudata, L. lorquini, A. bredowii, A. halesus, P. ruralis,* and *P. melane.* Species exhibiting a marked decline over the years include *P. clodius, P. eurymedon, C. tullia, S. zerene, P. gracilis,* and *I. icarioides.* The commonest resident species are *S. callippe, S. hydaspe, E. chalcedona, E. editha, A. bredowii, L. arota, H. grunus, M. nelsoni, E. propertius, O. sylvanoides,* and *O. agricola.* Rarely-encountered species are *P. zelicaon, T. leanira, A. halesus, C. perplexa, L. spinetorum, E. tristis, E. brizo, P. ruralis, H. columbia,* and *P. melane.*

Flight Season

At Jerseydale, hibernants are the earliest to appear, often followed by *P. napi* and *C. argiolus* as the first butterflies to emerge in late February to mid April, depending on the year. In Skelton Canyon, first emergents precede Jerseydale's by about one to eight weeks, usually as *C. argiolus* and *P. sonorensis,* beginning in mid February to mid March. The peak in resident species diversity at Jerseydale is reached in late May to late June and at Skelton Canyon in mid May to mid June, when the greatest variety of annuals and perennials are in bloom. The last resident, nonhibernant butterflies of the season at Jerseydale are present until mid October to mid November, depending on the year, although hibernant *N. californica* fly as late as late October to late December. A few worn individuals of *C. sthenele* and *S. saepium* fly as late as mid August, one fair *S. hydaspe* and worn *H. grunus* into mid October, worn female *S. zerene* into late October, and worn

Table 2. Annotated checklist of resident (indigenous) butterflies from the survey area. J = Jerseydale (Yellow Pine Forest), F = Footman Ridge (YPF & Foothill Woodland), S = Skelton Canyon (Foothill Woodland & ecotone), A = all three localities (allochoric), u = univoltine. References relevant to some taxonomic decisions are cited.

Papilionidae

Parnassius clodius sol Bryk & Eisner—J,u
Papilio eurymedon Lucas—A
Papilio multicaudata Kirby—A
Papilio rutulus rutulus Lucas—J,S
Papilio zelicaon Lucas—S,F

Pieridae

Neophasia menapia menapia (C. & R. Felder)—J,F,u
Pontia sisymbrii sisymbrii Boisduval—S,F,u
Pieris napi castoria (Reakirt)—J,S (see Shapiro 1975; Ferris 1989)
Euchloe ausonides near *ausonides* (Lucas)—J,u
Euchloe hyantis hyantis (W.H. Edwards)—S,F,u
Anthocharis lanceolata lanceolata Lucas—S,u
Anthocharis sara sara Lucas—J,S

Satyridae

Coenonympha tullia california (Westwood)—A (see Porter & Geiger, 1988)
Cercyonis sthenele silvestris (W.H. Edwards)—A,u

Nymphalidae

Speyeria callippe inornata (W.H. Edwards)—J.,F,u
Speyeria hydaspe near *viridicornis* (J.A. Comstock)—J,F,u
Speyeria zerene zerene (Boisduval)—J,F,u
Thessalia leanira leanira (C. & R. Felder)—S,u (see Smith and Brock 1988)
Charidryas palla palla (Boisduval)—A,u
Phyciodes mylitta mylitta (W.H. Edwards)—A
Euphydryas chalcedona chalcedona (Doubleday)—S,u
Euphydryas editha rubicunda (Hy. Edwards)—S,u
Polygonia gracilis zephyrus (W.H. Edwards)—J (see Scott 1984)
Nymphalis antiopa antiopa (Linnaeus)—J,S
Nymphalis californica (Boisduval)—A
Limenitis lorquini lorquini (Boisduval)—J,S
Adelpha bredowii californica (Butler)—A

Lycaenidae

Lycaena arota arota (Boisduval)—J,F (see Ballmer and Pratt 1988)
Lycaena gorgon (Boisduval)—S,u
Habrodais grunus grunus (Boisduval)—A,u
Atlides halesus estesi Clench—J,F
Satyrium auretorum auretorum (Boisduval)—S,F,u
Satyrium californica (W.H. Edwards)—A,u
Satyrium saepium saepium (Boisduval)—S,F,u
Satyrium sylvinus near *sylvinus* (Boisduval)—J,S,u
Satyrium tetra (W.H. Edwards)—S,u
Callophrys perplexa near *perplexa* (Barnes & Benjamin)—S,u (see Ballmer and Pratt 1988)
Loranthomitoura johnsoni (Skinner)—J,u
Loranthomitoura spinetorum spinetorum (Hewitson)—J (see Ballmer and Pratt 1992)
Mitoura nelsoni nelsoni (Boisduval)—J,F,u
Incisalia augustinus iroides (Boisduval)—A (see Ferris 1989)
Incisalia eryphon eryphon (Boisduval)—J,u
Incisalia mossii near *windi* Clench—S,u
Everes amyntula amyntula (Boisduval)—A,u
Celastrina argiolus echo (W.H. Edwards)—A (see Eliot and Kawazoe 1983)
Philotes sonorensis sonorensis (Felder & Felder)—S,u
Glaucopsyche lygdamus near *incognitus* Tilden—J,S,u
Glaucopsyche piasus near *piasus* (Boisduval)—J,u
Icaricia icarioides icarioides (Boisduval)—A,u

Table 2. Continued.

Hesperiidae
Thorybes pylades (Scudder)—J,F,u
Erynnis persius ssp. (Scudder)—J,S
Erynnis propertius (Scudder & Burgess)—A
Pyrgus ruralis ruralis (Boisduval)—J,u
Hesperia harpalus near *yosemite* Leussler—A,u (see MacNeill 1964)
Hesperia juba (Scudder)—J,F
Ochlodes agricola nemorum (Boisduval)—S,u (see Emmel and Emmel 1973)
Ochlodes sylvanoides sylvanoides (Boisduval)—A,u
Poanes melane melane (W.H. Edwards)—J,S (see Burns 1992)
Amblyscirtes vialis (W.H. Edwards)—J,u

A. bredowii into early November (once in mid December). Several unusual autumn occurrences were a fresh female *M. nelsoni* in early October and a *C. argiolus* in mid October. By late October, most species encountered are the common weedy types. By late summer in Skelton Canyon, extremely dry conditions prevail and only three to seven resident species are present.

Dispersal and Behavior

Skelton Canyon (FW) resident species that occasionally or rarely disperse up into Jerseydale (casuals) are *P. sisymbrii, A. lanceolata, E. chalcedona, E. editha, L. gorgon, S. saepium, S. auretorum, S. tetra, C. perplexa, I. mossii,* and *O. agricola.* Jerseydale (YPF) resident species that rarely disperse down into Skelton Canyon are *P. clodius, S. callippe, L. arota, M. nelsoni, I. eryphon,* and *A. vialis.* Dispersal exchange of these casuals across the ecotone that separates the two plant communities appeared not to lead to their permanent establishment by colonization in the foreign community and, except for *A. lanceolata* and *E. editha,* is usually quite rare or at least not a very regular occurrence, with the ecotone exhibiting no edge effect here. 73% of the resident butterfly species are in common between Jerseydale and Skelton Canyon if casual exchange is included, but decreases dramatically to 44% if casuals are excluded. Species that overwinter as adults at Jerseydale include *P. gracilis, N. californica, N. antiopa,* and *V. atalanta* (see Scott 1979). Species exhibiting male hilltopping behavior on the highest summit of Footman Ridge (s = singletons) are *P. zelicaon, P. eurymedon, P. protodice* (s), *P. sisymbrii, S. callippe,* all four *Vanessa, S. saepium, T. pylades* (s), *E. propertius, E. tristis* (s), *E. brizo, H. harpalus,* and *H. columbia.* Although *L. johnsoni* frequents ridge summits in hilltopping behavior in Napa and Yolo counties (cf. Kelson and Minno 1983; Shields 1986), none was observed doing so on Footman Ridge. Migratory species (excluding strays) are *D. plexippus, N. californica,* and *V. cardui* (see Shields 1987; Giuliani and Shields 1995 for Jerseydale observations). In addition, occasional *H. ericetorum* were seen to rapidly migrate NW in the spring of 1985 and 1986. Strongly colonial species are *C. tullia, H. grunus, L. gorgon, S. sylvinus, E. amyntula, P. sonorensis, G. piasus,* and *I. icarioides.*

I saw most taxa visit flowers, but those that rarely or never did (at least in this area) were *Polygonia, Nymphalis, A. bredowii, L. arota, H. grunus, L. johnsoni,* and *P. sonorensis.* Flowers present that were especially attractive to butterflies include *Erysimum* L. (Brassicaceae); *Eriogonum* Michx. (Polygonaceae); *Arctos-*

Table 3. Annotated checklist of non-resident (immigrant) butterflies from the survey area. J = Jerseydale, F = Footman Ridge, S = Skelton Canyon, A = all three localities.

Papilionidae

Battus philenor philenor (Linnaeus)—J, one stray (12.VII.1983)

Pieridae

Pontia protodice Boisduval & Le Conte—J,F; occasional species
Pieris rapae (Linnaeus)—J,S; occasional species
Colias eurytheme Boisduval—A; frequent invasions, rarely overwinters
Zerene cesonia (Stoll)—S, one stray (15.IX.1983)
Zerene eurydice (Boisduval)—J, one vagrant
Phoebis sennae (Linnaeus)—J, one stray (2.V.1992)

Danaidae

Danaus gilippus strigosus (Bates)—J, three strays (16,21,23.X.1988)
Danaus plexippus (Linnaeus)—A; seasonal migrant, does not overwinter

Nymphalidae

Euptoieta claudia (Cramer)—J, one stray (23.X.1988) (see Shapiro et al. 1990)
Phyciodes pulchella pulchella (Boisduval)—J, one vagrant (see Scott 1994)
Polygonia faunus rusticus (W.H. Edwards)—J, one vagrant
Polygonia satyrus satyrus (W.H. Edwards)—J, several vagrants in 1983
Aglais milberti milberti (Godart)—J, one vagrant (see Miller and Miller 1990)
Vanessa annabella (Field)—A; occasional species, several migrating
Vanessa atalanta rubria (Fruhstorfer)—A; overwinters but absent in summer; several migrating in late April and early May
Vanessa cardui (Linnaeus)—A; seasonal migrant, does not overwinter
Vanessa virginiensis (Drury)—A, occasional species
Junonia coenia (Hübner)—A; common, opportunistic species, rarely overwinters (see Tilden 1973)

Libytheidae

Libytheana bachmanii larvata (Strecker)—J, one stray (13.X.1990)

Lycaenidae

Lycaena helloides (Boisduval)—J, occasional species
Strymon melinus pudica (Hy. Edwards)—A, occasional species
Brephidium exilis (Boisduval)—J, occasional species
Leptotes marina (Reakirt)—J,S; occasional species
Everes comyntas (Godart)—J,S; several vagrants in 1973
Icaricia acmon acmon (Westwood & Hewitson)—A; common, opportunistic species, rarely overwinters

Hesperiidae

Polygonus leo arizonensis (Skinner)—J, one stray (11.VIII.1984)
Erynnis brizo near *lacustra* (W.G. Wright)—F, occasional species (see Shields 1978)
Erynnis tristis tristis (Boisduval)—F,J; occasional species
Pyrgus communis (Grote)—A, occasional species
Heliopetes ericetorum (Boisduval)—A; seasonal migrant, sometimes fairly common, does not overwinter
Hylephila phyleus phyleus (Drury)—J, occasional species
Hesperia columbia (Scudder)—F, occasional species (see Shields 1978)
Atalopedes campestris campestris (Boisduval)—J, occasional species
Lerodea eufala (W.H. Edwards)—J, occasional species

taphylos Adans. (Ericaceae); *Apocynum* L. (Apocynaceae); *Asclepias* L. (Asclepiadaceae); *Phlox* L. (Polemoniaceae); *Eriodictyon* Benth. and *Nemophila* Nutt. ex Barton (Hydrophyllaceae); *Monardella* Benth. (Lamiaceae); *Chamaebatia* Benth. and *Prunus* L. (Rosaceae); *Cercis* L. and *Lupinus* L. (Fabaceae); *Ceanothus* L. (Rhamnaceae); *Aesculus* L. (Hippocastanaceae); *Lomatium* Raf. (Apiaceae); *Achillea* L., *Cirsium* Mill., *Haplopappus* Cass., and *Wyethia* Nutt. (As-

teraceae); and *Brodiaea* Sm. (Amaryllidaceae). Species especially fond of visiting mud are *N. californica, A. bredowii, L. arota, A. halesus, L. spinetorum,* and *L. johnsoni* (both sexes, to replenish water-loss); and *E. amyntula, C. argiolus,* and *I. icarioides* (males only, to restore sodium-loss) (see Adler and Pearson 1982). The shade-loving species are *C. sthenele* and *H. grunus.* The meadow species are *E. ausonides* and *C. tullia.* Riparian species are *P. rutulus, P. multicaudata, N. antiopa, L. lorquini, S. sylvinus, A. vialis,* and *P. melane.* Species that fly over exposed rocky, south-facing canyon slopes are *P. sisymbrii, E. hyantis,* and *P. sonorensis.*

A few possible foodplants were recorded (see also Bionomics section). A worn female *N. californica* was seen attempting to oviposit on *Ceanothus cuneatus* (Hook.) Nutt. A larva found on the outer leaves of *Holodiscus boursieri* (Carr.) Rehd. (Rosaceae) in a sunlit gully in deep forest produced an *L. lorquini* adult. The two violets in the forest where *S. zerene* and *S. hydaspe* fly are *Viola lobata* Benth. and *V. purpurea* Kell. (Violaceae). *H. grunus* adults are closely associated with *Quercus chrysolepis* Liebm.

Bionomics

A more detailed accounting of the bionomics of 22 resident species is presented below for the survey area.

1. *Parnassius clodius sol.*—Flew from late May to late June. In 1956–58, it was fairly common in forest openings along Skelton Creek where *Dicentra formosa* (Andr.) Walp. (Fumariaceae) occurs. It then declined to one to two individuals per season in the 1960's and early 1970's and was last sighted there in 1983. Its extirpation was probably due to low population levels from the 1958–59 and 1960–61 droughts that were subsequently subjected to double the average precipitation in 1982–83. Adults like to nectar on the flowers of *Wyethia angustifolia* (DC.) Nutt.

2. *Papilio zelicaon.*—Flies in early April to late May (residents), and apparently as vagrants in late July to late August, and is always rather scarce. One female oviposited on *Lomatium utriculatum* (Nutt.) C. & R. (Apiaceae) in Skelton Canyon (Emmel and Shields 1978). Native California umbels produce univoltine *P. zelicaon,* while multivoltine populations use non-native hosts in lowland areas (Sims 1983).

3. *Papilio multicaudata.*—Flies from late April to mid September and is multivoltine. The males patrol along Skelton Creek and forest gullies, and adults nectar on *Cirsium.* Females are occasionally orange. Usually not more than one or two are found on any given day.

4. *Neophasia menapia.*—The flight usually begins in late June and lasts two to four weeks. Males emerge first and reach peak numbers within five to 10 days when the first females emerge. Males actively fly around *Pinus ponderosa,* usually high up, patrolling for perched females, from 7:00 AM to 6:00 PM. Both sexes occasionally descend to the forest floor to nectar on the flowers of Bear Clover *(Chamaebatia),* Blackberry *(Rubus* L., Rosaceae), etc., or to fly in the shade. Occasional wings and dead individuals on the ground and beak-marked wings suggest a fair amount of bird predation. They became very common in 1981 and 1983.

5. *Pieris napi.*—Form *microstriata* J.A. Comstock is sometimes fairly common

and flies from early March to mid May in Skelton Canyon and from late March to early June at Jerseydale, while typical *castoria* is very rare (c. 0.01%) and occurs in late May to late June at Jerseydale. It frequents streamsides where its *Cardamine breweri* Wats. (Brassicaceae) foodplant grows, is fond of nectaring on the flowers of *Arctostaphylos mariposa,* and flies from 9:00 AM to 4:00 PM.

6. *Euchloe ausonides.*—Flies from early April to late May, peaking in early May. It is a resident, flying rapidly over the open, flowery meadows, but is also sometimes associated with *Brassica geniculata* (Desf.) J. Ball. (Brassicaceae) in weedy habitat late into its flight period. The first individuals to appear are fresh, however, and probably utilize a native crucifer. One specimen (5.V.1974) had a nearly solid green underside.

7. *Anthocharis lanceolata.*—On the wing from early April to early June, and is not very common. Males often fly up and down ravines on the southeast-facing slopes of Skelton Canyon, and one was observed to avidly nectar on the purple flowers of its foodplant, *Arabis sparsiflora* Nutt. in T. & G. (Brassicaceae).

8. *Speyeria callippe inornata.*—Males fly from late May to late July, females from mid June to mid August. Adults are occasionally common and inhabit open areas in the forest and forest margins and sometimes hilltop. It frequently nectars on *Monardella, Wyethia,* and sometimes *Cirsium,* and the violet where it flies is *Viola quercetorum* Baker & Clausen.

9. *Speyeria hydaspe viridicornis.*—Males fly from early June to early August, females from mid June to mid August. Adults fly along forest paths, margins, and clearings and frequently nectar at *Monardella, Wyethia,* and *Apocynum.* Males sometimes fly close to the ground and around small trees, apparently searching for females. One copulating pair was located at 11:05 AM at mint beds (female carried male). It is fairly common.

10. *Lycaena arota.*—Has an extended summer flight from mid June to early September. Both sexes are drawn to mud that is in full sunlight along the creeks and stock pond dams in the hot summer afternoons and are sometimes abundant.

11. *Loranthomitoura spinetorum.*—Is bivoltine at Jerseydale, flying from late April to mid June and mid July to mid August, mostly at mud in the afternoon along creeks and earthen dams.

12. *Loranthomitoura johnsoni.*—The flight lasts from mid July to mid August. Most captures are from sunlit muddy places along Skelton Creek bordered by Incense Cedar-White Fir forest slopes, from 8:30 AM to 3:00 PM, rarely nectaring on watercress. Males and females are about equal in numbers. 1956 and 1963 were its peak years, which were normal precipitation years preceded by three to four subnormal precipitation years. The foodplant at Jerseydale remains unknown. Older females confined with *Arceuthobium campylopodum* Engelm. in Gray (Loranthaceae) and *Phoradendron juniperinum* var. *libocedri* Engelm. in Wats. (Loranthaceae) (which grows on Incense Cedar) reluctantly laid a few ova on each but refused *Arceuthobium abietinum* f. sp. *concoloris* Hawksworth & Wiens and *A. tsugense* (Rosendahl) Jones (cf. Hawksworth and Wiens 1972). One worn female hovered around very small Incense Cedars (2:30 PM, 25.VII.1976) in a clearing where only these small trees are growing commonly. Only the light-colored summer form is present at Jerseydale (see Shields 1965).

13. *Mitoura nelsoni.*—Flies from late April to late June (to mid July in 1963), peaking in late May. Adults nectar on a wide variety of flowers, particularly

Achillea, Ceanothus integerrimus, Chamaebatia, Potentilla L. (Roseaceae), *Prunus,* and *Wyethia,* visit mud, and are often common (almost swarming on *Chamaebatia* in late June of 1961). One copulating pair was observed at 10:50 AM on 25.V.1974 in an area with lots of young *Calocedrus* Kurz. (male carried female).

14. *Incisalia mossii windi.*—Flies only in April and nectars on *Lomatium utriculatum* and *Pseudobahia heermannii* (Durand) Rydb. (Asteraceae). The main colony is located about half-way down Skelton Canyon at 825–885 m, with occasional vagrants found further up the canyon. Females differ from typical *windi* in having a greenish-brown upperside and a golden underside with a pronounced white line. The foodplant here may be *Sedum spathulifolium* ssp. *anomalum* (Britton) Clausen & Uhl (Crassulaceae) which grows on steep, shady, north-facing rocky places immediately adjacent to the main colony of *windi.*

15. *Philotes sonorensis.*—Flies at an isolated colony in Skelton Canyon from mid February to late April, peaking in late March to mid April. It emerges when its foodplant, *Dudleya cymosa* (Lem.) Britt. & Rose (Crassulaceae), is about half-grown and stops flying about one to two weeks before *Dudleya* Britt. & Rose anthesis.

16. *Glaucopsyche piasus.*—Flies from early May to mid June. Adults visit lupines *(Lupinus),* other flowers, and mud in direct association with the far more numerous *I. icarioides.* It is perhaps most closely associated with *Lupinus albicaulis* Dougl. ex Hook. that grows in isolated patches in forest clearings. 1981 and 1983 were its peak years, although it is never very common.

17. *Thorybes pylades.*—Flies from early May to late June and is seldom common. Adults are found around *Lathyrus nevadensis* Wats. and *L. paucifolium* Fern. ssp. *brownii* (Eastw.) Piper (Fabaceae) in the forest understory, visit mud, and occasionally hilltop.

18. *Pyrgus ruralis.*—A total of eight specimens were collected, always in mid to late May, in 1974, 1981, 1983, 1985, and 1994. Flight is low to the ground near patches of *Potentilla glandulosa* Lindl. (Rosaceae) in forest clearings and small gullies, and it sometimes visits mud.

19. *Hesperia juba.*—Is bivoltine, flying from early May to mid June and late August to mid October. Males are sometimes territorial at a particular low spot in the meadow next to a small gully, and adults visit the blooms of *Haplopappus arborescens* (Gray) Hall on Footman Ridge. It is usually fairly scarce but became common in mid September of 1985.

20. *Hesperia harpalus yosemite.*—Flies from early September to mid October, peaking in mid September. Though only rarely found in Skelton Canyon and Jerseydale, it is sometimes fairly common on *Haplopappus* blooms on Footman Ridge where the males are territorial while nectaring and perching along the ridgetop.

21. *Poanes melane.*—Flies in early May to mid June and again in mid September, with few encountered over the years. Males are closely associated with sedgy places along Skelton Creek for 2 km. Its habits at Jerseydale favorably compare with those of *P. melane vitellina* (Herrich-Schäffer) in southeastern Arizona, i.e. a scarce, riparian, canyon-bottom dweller (see Bailowitz and Brock 1991). Some of the earliest California records (1871) are from the Yosemite area, further indicating that its populations are resident in this region (Heppner 1971).

However, the adults also visit flowers in waste areas in the fall, perhaps from immigration.

22. *Amblyscirtes vialis.*—Flies from mid April to late June and is occasionally common. It inhabits shaded creeks, forest clearings, dry gullies, and bends in the dirt roads. One copulating pair was observed at 5:25 PM.

Discussion

The only resident taxa ecotypes that are confined to the YPF plant community at Jerseydale are *P. clodius sol* and *G. piasus* (western foothill segregate). *Colias occidentalis chrysomelas* Hy. Edwards frequents the YPF in northern California (Garth and Tilden 1963; Shapiro et al. 1979; Ferris, 1993; personal observations) and also inhabits the Douglas-Fir Forest *(Pseudotsuga menziesii)* (Howe 1975), both of which are in the Transition Zone, and *Speyeria cybele leto* (Behr) may be another Transition Zone indicator (Garth and Tilden 1963; Shapiro et al. 1979; personal observations). The geographic ranges of all four are certainly narrower than their hostplant ranges, suggesting that climatic-physiologic adaptation may be restricting them to the Transition Zone environment.

Probable indicator taxa of the FW (and chaparral) that are present in the survey area include *Z. eurydice, T. leanira leanira, E. chalcedona chalcedona, E. editha rubicunda, L. gorgon, S. auretorum, S. tetra, S. saepium, C. perplexa, P. sonorensis, E. tristis, E. brizo lacustra, H. columbia,* and *O. agricola* (cf. Shields 1986). In addition, *A. lanceolata* and *C. sthenele silvestris* are found especially in the Upper Sonoran Zone but are occasionally met with in the Transition Zone (the "selective" indicator category of Oosting 1956).

Paleobotanically, the dominant species of the YPF plant community first appeared in the Sierra Nevada in Kern and Alpine counties during the Middle and Late Miocene, prior to the major uplift of the range during the Pliocene and Early Pleistocene (Axelrod 1957, 1980). The present-day YPF plant community developed at the borders of the mixed conifer forests during the Holocene when such genera as *Dicentra, Lathyrus* L., *Potentilla, Ribes* L., and *Viola* L. radiated into the drier, bordering vegetation with the opening up of this new subzone (cf. Axelrod 1976; Raven and Axelrod 1978; Van Devender et al. 1987). The history of the FW plant community is outlined in Shields (1986) and extends back to Late Miocene times in central California. The large number of butterfly indicator species inhabiting the FW plant community compared with the remarkedly few ecotypes confined to the YPF plant community in California suggests that the former are pre-Pleistocene relics while the latter evolved quite recently during the Late Quaternary.

Of the 44 resident species found in the YPF plant community at Jerseydale, two are indicators and 18 occur from the Upper Sonoran to at least the Canadian life zone (sometimes higher) and show no fidelity to any particular plant community (e.g. *P. rutulus, L. lorquini, L. johnsoni, T. pylades,* etc.), with *A. halesus* descending into the Lower Sonoran. Of the remainder, one group of 14 species also flies in the Upper Sonoran Zone: *P. eurymedon, P. multicaudata, P. napi, E. ausonides, A. sara, A. lanceolata, C. tullia, L. arota, I. augustinus, S. californica, S. sylvinus, G. lygdamus, O. sylvanoides,* and *P. melane. S. callippe inornata* generally occurs above the FW plant community and likes drier sites such as forest openings and forest margins within the YPF plant community. However, it

also frequents the YPF/FW ecotone and the contact zone between these plant communities, making its ecological preference difficult to classify. The other group (nine species) occurs from the Transition Zone to at least the Canadian Zone: *N. menapia, S. zerene, S. hydaspe, P. gracilis, M. nelsoni, I. eryphon, P. ruralis, H. harpalus,* and *A. vialis* (cf. Garth and Tilden 1963; Shields 1966, 1986). Thus it appears that all of the resident butterfly species of the YPF plant community were fed directly in from the Upper Sonoran and Canadian Zones which border it.

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John F. Emmel, David Hartesveldt, June McCaskill, James L. Reveal, and some members of the U.C. Davis Botany Department determined certain plants; Eldridge M. Moores identified some rock samples; Arthur M. Shapiro and John M. Burns identified *Pieris napi* forms and *Erynnis persius,* respectively; John F. Emmel provided useful comments to the taxonomic lists; and the U.S. Forest Service at Jerseydale furnished the precipitation data. The manuscript was reviewed by Julian P. Donahue, John F. Emmel, Glenn A. Gorelick, James A. Scott, and Arthur M. Shapiro. I am indebted to all of the above for their expertise and generous assistance.

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Notes on the Distribution of Two Lithodid Crabs (Crustacea: Decapoda: Anomura) from off the Coast of Baja California Sur, México

Joel W. Martin,[1] Carlos A. Sánchez,[2] and Ricardo Pereyra[2]

[1] *Natural History Museum of Los Angeles County, 900 Exposition Boulevard, Los Angeles, California 90007, U.S.A.*
[2] *Universidad Autonoma de Baja California Sur, Depto. de Biología Marina, La Paz, Baja California Sur, México*

Abstract.—Surveys designed to investigate species of potential fisheries interest off the coast of Baja California Sur, México, have revealed the presence of two lithodid crabs (Crustacea, Decapoda, Anomura). One species, *Lithodes couesi* Benedict, 1895, is represented in the collections by 22 individuals and is reported from México for the first time, extending the known range of the species southward from off San Diego, California. The second species, *Glyptolithodes cristatipes* (Faxon, 1893), has been reported previously from mostly more southern localities (Perú and Chile), and is represented by a single adult male. Remarks on a heavy infestation of a sacculinid parasite of *L. couesi* and on morphological changes during ontogeny in *G. cristatipes* are included.

The anomuran crab genus *Lithodes* includes 18 species in the Pacific (Macpherson 1991), 16 of which are known to occur in the eastern Pacific. Eight of these species occur in the northern hemisphere, including *Lithodes couesi* Benedict, 1895 (Wicksten 1989). Hendrickx (1993) reported only 6 species for the Mexican Pacific, all distributed off the coasts of the Baja California Peninsula, but did not include *L. couesi,* the southern-most record of which was San Diego, California, prior to this report (Schmitt 1921; Wicksten 1989). The monotypic genus *Glyptolithodes,* containing only *Glyptolithodes cristatipes* Faxon, 1893, has been reported from this region previously (see Hendrickx 1993). However, *G. cristatipes* apparently is rare, being predominantly a more southern species, although records exist for southern California: off the Palos Verdes Peninsula, Santa Catalina Island, and Coronado Bank (Wicksten 1982) and from the La Jolla and Redondo Submarine Canyons (see Materials examined under *G. cristatipes*). In this paper we document the occurrence of both species off the coast of Baja California Sur, México, and include natural history observations of both species.

Materials and Methods

Specimens of both species were collected during a preliminary survey of the crustaceans of potential fishery interest off the coast of Baja California Sur, by personnel of the Universidad Autonoma de Baja California Sur (UABCS) aboard the R/V "El Puma" during 1995. A total of 22 *Lithodes couesi* and one *Glyptolithodes cristatipes* were collected on May 21, 1995, on PUMA Cruise 9505, by baited traps lowered to different depths (see Material examined). All specimens were sexed, weighed, and preserved in a 4% formaldehyde solution at the

UABCS, and later transferred to 70% ethanol. Measurements (carapace width, carapace length) were obtained using vernier calipers. Two specimens of *L. couesi* (LACM 95-94.2) and the single specimen of *G. cristatipes* (LACM 95-94.1) are housed in the Crustacea collections of the Natural History Museum of Los Angeles County (LACM). All other specimens are housed at the UABCS. Two additional specimens of *G. cristatipes* from off southern California were borrowed from the Marine Biological Laboratory of the Los Angeles County Sanitation District through the kindness of Don Cadien.

Lithodes couesi Benedict, 1895
Fig. 1

Lithodes couesi Benedict, 1895: 481; Bouvier 1895: 10, 11, 28; Rathbun 1910: 166; Schmitt 1921: 162, pl. 28–29, figs. 3–5; Makarov 1939: 255, fig. 101; Sakai 1971: 13–14, pl. V, XIII; Hart 1971: 1543, 1982: 63, 94; Somerton 1981: 259; Wicksten 1982: 245, 1989: 303, 314; Dawson and Yaldwyn 1985: 101, fig. 18; Dawson 1989: 317.

Previous records.—Japan: off Onahama, and Hokkaido, depth unrecorded (Sakai 1971). Bering Sea: north of Unalaska and off Shumagin Bank, 399 and 625 fms (1125 m) (Benedict 1895); 58°N, 600–1400 m (Bouvier 1896); Bering Sea to off San Diego, 301 to 530 fms (542–954 m) (Schmitt 1921). Alaska: central Gulf of Alaska, on seamounts (Somerton 1981). British Columbia: Dixon Entrance, 54°32′00″N, 132°05.3′W, 258 m (Hart 1971); Queen Charlotte Islands, 53°00.8′N, 132°55.8′W, 1076 m (Hart 1971); west of Vancouver Island, Tasu Sound, Englefield Bay (Hart 1982). Southern California: southern islands and banks, 500–1000 m and 1000+ m (Wicksten 1982); off San Diego (Wicksten 1989).

Material examined.—PUMA Cruise 9505, Station 3, May 21, 1995, 27°22′29″N, 115°00′28″W, south of Bahia Tortugas, Baja California Sur, México, 740 m; 16 females, carapace width 92 mm to 123 mm (average 104.5 mm), carapace length 95 mm to 127 mm (average 111.2 mm); 6 males, carapace width 89 mm to 126 mm (average 106.6 mm), carapace length 85 mm to 129 mm (average 109.6 mm).

Distribution.—from off Onahama, Japan (Sakai 1971), to Bering Sea and Alaska, to south of Bahia Tortugas, Baja California Sur, México (this report), 258 to 1829 m.

Remarks.—There have been few additional distributional records of this species since its original description. The most southern limit recorded prior to this study was off San Diego (see Wicksten 1989). Our collections constitute a new distributional record of the species in México, and the most southern limit of the species in the Pacific, extending the known range approximately 640 km southward. The lack of any records of this species among those of deep water decapods of this region may be an artifact of sampling; Somerton (1981) remarked that "benthic sampling surveys infrequently reach the depth inhabited by *L. couesi.*"

Although identification of our specimens as *L. couesi* was relatively easy, the species exhibits some morphological variation that has not, to our knowledge, been reported previously. The rostral length and to a lesser degree its shape can

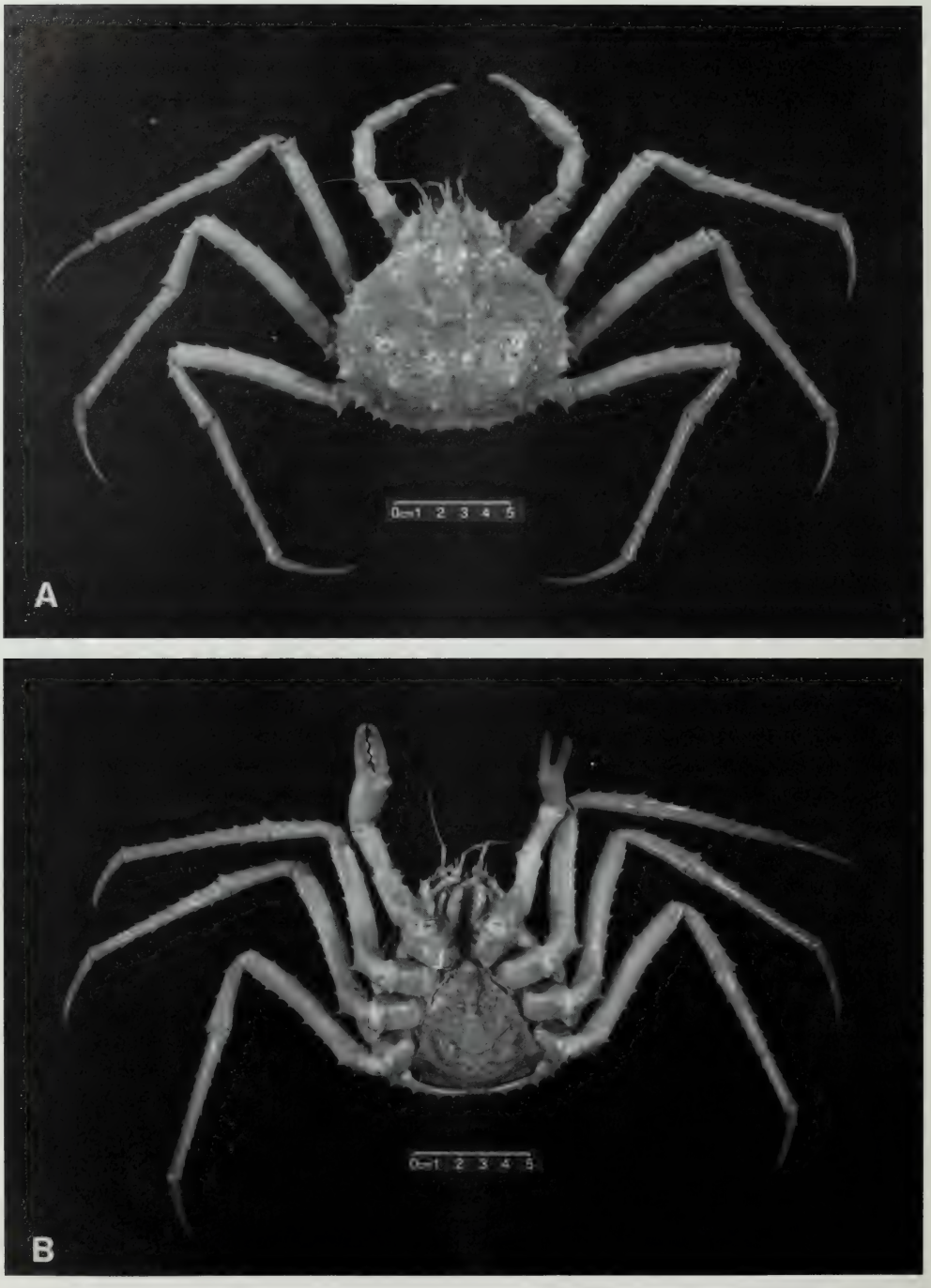


Fig. 1. *Lithodes couesi* Benedict from off Baja California Sur, México, adult male. A, dorsal view, B, ventral view.

Fig. 2. *Glyptolithodes cristatipes* (Faxon) from off Baja California Sur, México, adult male. A, dorsal view, B, ventral view.

vary appreciably. Similarly, the characteristic lateral spines of the carapace can also vary, being longer and more acute in some specimens than in others.

Our collections showed heavy infestation by what we assume is the rhizocephalan barnacle *Briarosaccus callosus* Boschma, 1962. This species has been reported to parasitize *L. couesi* previously (Boschma 1970; Somerton 1981; Hawkes et al. 1985). However, this is the first report of this association in Mexican waters (because it is the first record of the host). More important perhaps is the very high incidence of parasitism. In the only study of the life history of *L. couesi,* Somerton (1981) reported an incidence of parasitism by *B. callosus* of only 0.7% in a collection of 674 individual *L. couesi.* Our collections differ dramatically in that, while only 22 specimens were collected, nearly 55% (12), all females, were parasitized. We found no parasitized males.

Although the date of publication stamped on the page headings of Benedict's paper is 1894, the volume appears to have been published later, in 1895, and that year appears on the cover of bound editions of the entire volume. Additionally, in original versions of the entire volume, the title of Benedict's paper in the Table of Contents is followed by a publication date of January 29, 1895. According to the ICZN rules of nomenclature (ICZN 1985:43, Article 21(d) and Recommendation 21F), the 1895 date must be upheld.

Glyptolithodes cristatipes (Faxon, 1893)
Figs. 2, 3

Rhinolithodes cristatipes Faxon 1893: 163; Faxon 1895: pl. 7, figs. 2, 2a–c; Bouvier 1896: 28.

Glyptolithodes cristatipes.—Faxon 1895: 43; del Solar 1972: 13; Haig 1974: 161, 162; del Solar 1981: 4, 5; Wicksten 1982: 245, 247; Andrade 1987: 80; Macpherson 1988: 23, fig. 9; Dawson 1989: 317; Wicksten 1989: 303, 304, 306, 314; Hendrickx 1993: 283, 309.

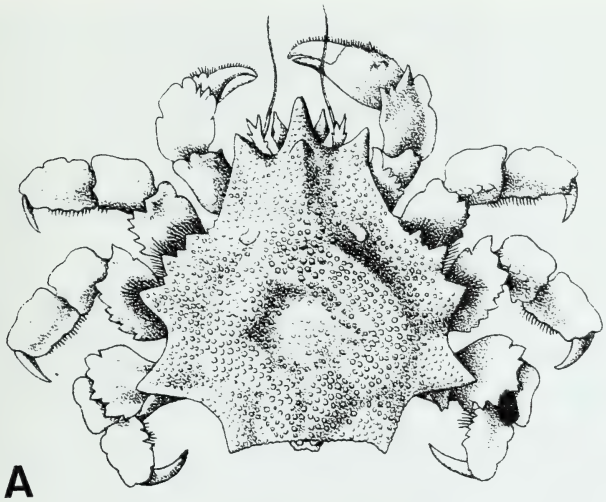
Glyptholithodes cristatipes.—Dawson and Yaldwyn 1985: 100 (typographical error), fig. 48.

Rhinolithodes (*Glyptolithodes*) *cristatipes.*—Bahamonde 1967: 3, pl. 1.

Previous records.—Panama: off Mariato Point, 07°09′45″N, 80°50′W, 322 fms (594 m) (Faxon 1893, 1895). Perú: south of Banco de Mancora, 400 m (del Solar 1972); off northern Perú, 03°51′S, 81°18′W, 800 m (del Solar 1972); off Puerto Chicama, 07°42′S, 80°26′W, 693 m (del Solar 1972); off Taltal, 25°11′S, 70°31′W, 245–266 m (Bahamonde 1967); at 06°31.5′S, 81°01.5′W, 712–744 m (Haig 1974). Chile: off Iquique, Chile, depth not recorded (Bahamonde 1967); off Coquimbo, Los Vilos, Pichidangui, Papudo, and Quintero, Chile, 29°58′S to 32°42′S, 250–480 m (Andrade 1987). California: off east end of Santa Catalina Island, 702 m; off Palos Verdes Peninsula, 33°33.5′N, 118°15.7′42″W, 462 m; and from Coronado Bank, 183 m (Wicksten 1982); off Palos Verdes Peninsula, south slope of Redondo Submarine Canyon, California, 33°49.08′N, 118°27.09′W (trawl mid-

→

Fig. 3. Changes in carapace shape and pereiopod length and width in developing *Glyptolithodes cristatipes* (Faxon). A, juvenile (from Faxon 1895). B, older male specimen (from Haig 1974). Compare B to photograph in Fig. 2A, a larger adult with less evidence of spination on carapace borders.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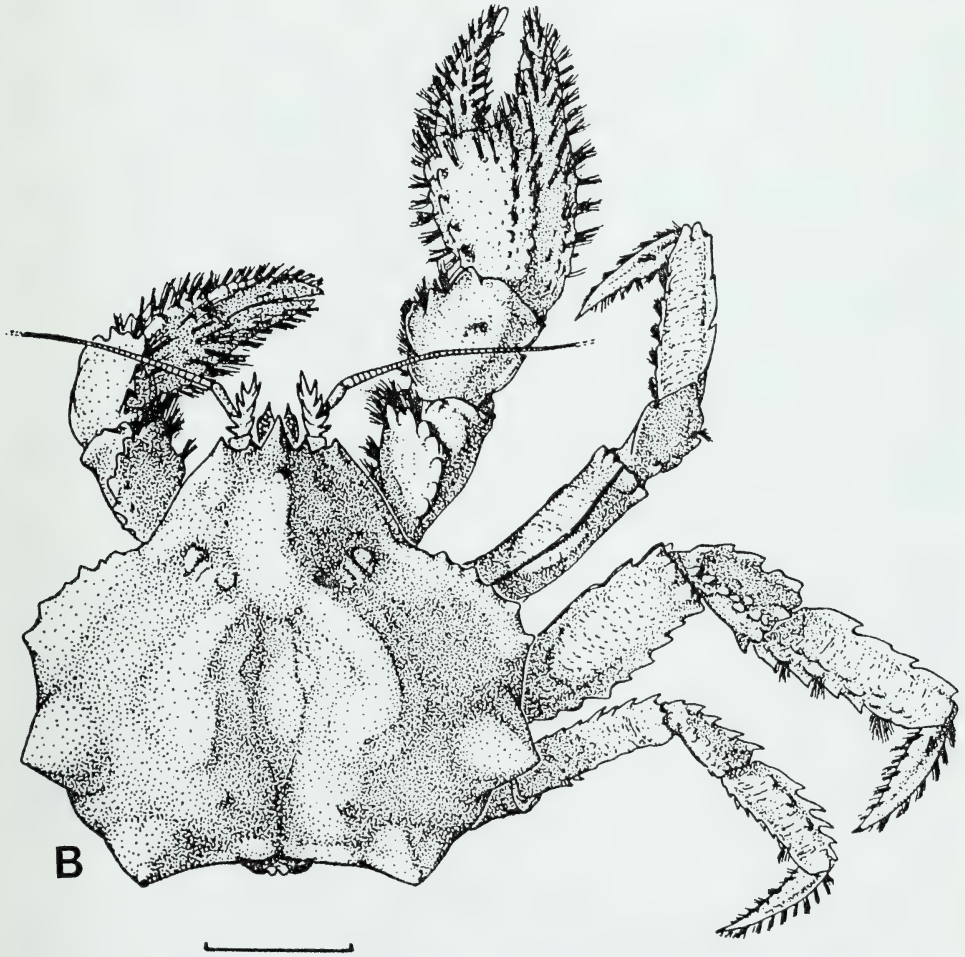
B

point), 305 m, station TO-1000, 21 Aug 1992 (County Sanitation Districts of Los Angeles County collections; D. Cadien, pers. comm.). México: west coast of Baja California Peninsula as far south as Bahia Magdalena; on the mainland from Cabo Corrientes south to the Mexican–Guatemalan border (extrapolated; no specimens known from that region) (Hendrickx 1993).

Material examined.—PUMA Cruise 9505, Station 3, May 21, 1995, 27°22′29″N, 115°00′28″W, south of Bahía Tortugas, Baja California Sur, México, 740 m; 1 male, carapace width 97.4 mm (measured at the widest point, which is at the last of a series of spines on the lateral carapace margin), carapace length 89.9 mm (including rostrum). Off Palos Verdes Peninsula, south slope of Redondo Submarine Canyon, California, 33°49.08′N, 118°27.09′W (trawl midpoint), 305 m, station T0-1000, 21 Aug 1992; 1 female, carapace width 63.5 mm, carapace length 61.9 mm (collection of the Marine Biology Laboratory, Los Angeles County Sanitation District). La Jolla Submarine Canyon, ROV dive no. 160, 550 m, 28 Oct 1995, 1 male, carapace width 64.3 mm, carapace length 63.8 mm (voucher collection for deep-sea videotapes at Scripps Institution of Oceanography, La Jolla, California).

Distribution.—From Palos Verdes Peninsula, California, USA (Wicksten 1982 and this report), to Quintero, Chile (Andrade 1987), 183–800 m.

Remarks.—Adults and juveniles show may differences, some of which were pointed out by Haig (1974). These differences include the following: "The carapace is broader than long instead of about as long as broad; the setae which decorate its lateral prominences in juveniles are absent in adults. There are three or four spines, instead of two, on each antennal acicle. The walking legs are much longer than the carapace width, and the various articles of these legs are proportionately more elongate than they are in juveniles" (from Haig 1974). In fact, even Haig's specimen appears to be less mature than our single male, prompting us to offer the following comparison to facilitate identification of this species at various stages. The overall spination appears to decrease in size as the crabs age, with older individuals (Fig. 2) appearing nearly circular in carapace outline as compared to younger specimens (Figs. 3A, B). (A decrease in spination with ontogeny appears to be true for lithodids in general, and is particularly obvious in some species, such as *Lithodes panamensis* Faxon; e.g., see del Solar 1981: 9.) The relative length of the appendages increases with age, resulting in an adult that is more "spider-like" than the rather short and stout juvenile. Indeed, were it not for the fact that virtually no other deep sea decapod in this region is remotely similar to either adults or juveniles of *G. cristatipes,* we would still be somewhat hesitant to assign juveniles and adults to the same species.

In the original description, the specimen was placed in the genus *Rhinolithodes* (Faxon 1893). Because he "had seen neither specimen nor figure of the type of this genus" he later (Faxon 1895) removed it to a separate genus, *Glyptolithodes,* once it became clear to him that *Rhinolithodes* was morphologically quite different. Bouvier was apparently unaware of this development when he wrote his 1896 paper.

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providing specimens from southern California for comparison. We also thank Dan Watson of the Photography Division of the Natural History Museum of Los Angeles County for the photographs, Gerald J. Bakus of the University of Southern California for assistance during the visits of C.A.S. and R.P. to Los Angeles, and the National Science Foundation's USAID/México program for financial support for travel. Finally, we thank Don Cadien, Tim Stebbins, and an anonymous reviewer for helpful comments on the manuscript.

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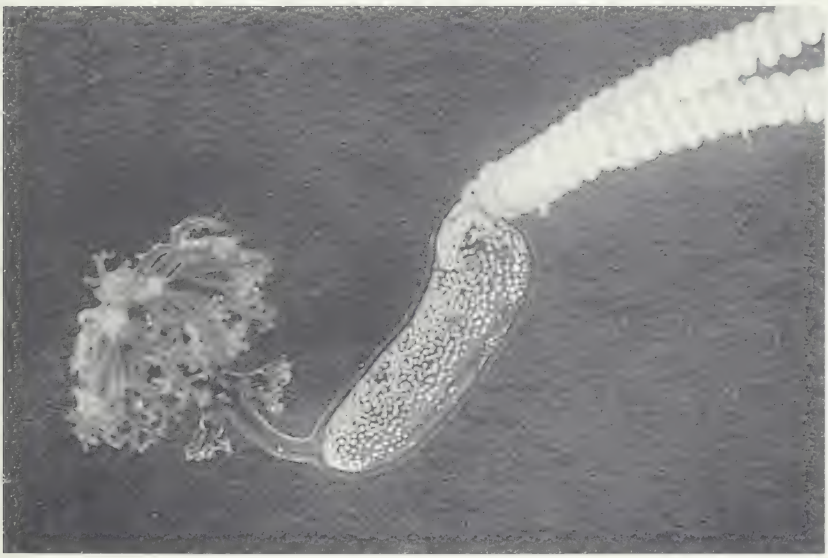

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SAMPLE ABSTRACT & INFORMATION

MICROBIAL ACTIVITY IN THE DIGESTIVE TRACT OF THE HALFMOON, ***Medialuna californiensis.*** J. S. Kandel[1], J. R. Paterek[2] and M. H. Horn[1], [1]California State Univ. Fullerton, CA 92634 and [2]Agouron Institute, La Jolla, CA 92037.

We report the presence of a diverse microbial flora and of microbial fermentation products in the hindgut region of the halfmoon, ***Medialuna californiensis,*** a seaweed-eating fish from southern California coastal waters. Viable aerobic and anaerobic bacteria were found in all sections of the gut, but were of highest concentration (10^5–10^8/ml) in the hindgut. Microscopy revealed vibrios, spirilla, rod-shaped bacteria and flagellated protozoa in the midgut and hindgut, but primarily vibrios and rods in the stomach and foregut. Acetic, isobutyric and butyric acids, the volatile products of microbial breakdown of carbohydrates, were found only in the hindgut, as was ethanol, a nonvolatile product. These results provide the first evidence for microbial fermentation and its possible contribution to the energy supply in a north-temperate herbivorous fish.

1. Judy S. Kandel, Department of Biology, California State University, Fullerton, Fullerton, CA 92634, 714-773-2546. FAX 714-773-3426, jkandel@fullerton.edu. Nonmember

2. J.R. Paterek, Agouron Institute, La Jolla, CA 92037. Nonmember
   Michael H. Horn, Department of Biology, California State University, Fullerton, Fullerton, CA 92634, 714-773-3707. Member

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Host–Parasite Relationship of the Copepod Eye Parasite, *Phrixocephalus cincinnatus,* and Pacific Sanddab (*Citharichthys sordidus*) Collected from Wastewater Outfall Areas

Penny Sue Perkins and Robin Gartman*

Corresponding Author: Penny Sue Perkins, Veterans Affairs Medical Center, 3350 La Jolla Village Dr. (9111-D), San Diego, California 92161
**Environmental Monitoring Division, City of San Diego*

Abstract.—The host–parasite relationship of *Phrixocephalus cincinnatus* and the Pacific sanddab, *Citharichthys sordidus,* was examined relative to season and distance from effluent discharge sites of wastewater treatment plants located off the coast of southern California. Pacific sanddabs were collected by otter trawl on a quarterly basis from waters off Los Angeles and San Diego. Infection with *P. cincinnatus* occurred in sanddabs ranging in size from 4.5–24.0 cm standard length. The prevalence of *P. cincinnatus* was higher on the Palos Verdes shelf (1.86%, measured from 1975 to 1995) and in Santa Monica Bay (1.34%, measured from 1989 to 1994) than off Point Loma, San Diego (0.54%, measured from 1992 to 1994). In 1995, prevalence of *P. cincinnatus* off San Diego increased to 1.90%. On the Palos Verdes shelf and off San Diego, prevalence of *P. cincinnatus* was highest in the winter and spring. In Santa Monica Bay, infection peaked during the summer months, and was highest at stations nearest to effluent discharge. Several new host records for *P. cincinnatus* are reported.

Phrixocephalus cincinnatus Wilson, 1908 is a blood-feeding parasitic copepod belonging to the family Pennellidae. The family includes some of the largest and most devastating parasites of economically important fishes. Pennellids feed primarily on the blood and tissue fluids of their hosts. Infection with pennellid copepods can result in severe pathological conditions such as anemia, reduced fat content in liver and skeletal muscle, delayed onset of maturity, reduced fecundity and castration (Kabata 1970). In addition, pennellids are a cause of high mortality rates of certain species of young fish.

Pennellids are unique among the parasitic copepods of fish because most species require an intermediate host to complete their life cycle. After hatching, free-swimming copepodids locate an appropriate intermediate host, and attach to an epithelial surface by means of a frontal filament. Development through several chalimus stages and copulation between adult males and preadult females occur on the intermediate host. Only the postmated female infects the final fish host. Although the intermediate host(s) and early developmental stages of *P. cincinnatus* are unknown, the minute, postmated female completely enters the eye through the cornea and begins metamorphosing as it traverses the globe. Kabata (1967, 1969) described the metamorphosis of the juvenile female within the eye of the flatfish host. During these early stages of infection, it is impossible to determine if a fish is infected without dissecting the eyes. Ultimately, the head and attachment organ of adult *P. cincinnatus* become embedded in the choroid,

and the large genital segment and eggstrings protrude from the eye. The parasite induces proliferation of the choriocapillaris resulting in the formation of a large hematoma upon which it feeds (Kabata 1970; Perkins 1994).

Off the coast of California, *P. cincinnatus* infects the eyes of the Pacific sanddab (*Citharichthys sordidus* Girard). Although Pacific sanddab is a commercially important species in northern California (Rackowski and Pikitch 1989), little is known regarding the effects of the eye parasite on the physiology of the fish. Ongoing environmental monitoring programs, designed to assess the status of the marine habitat off southern California, provided us with the opportunity to examine the host–parasite relationship of *P. cincinnatus* and Pacific sanddab. Although infection of sanddabs with the parasite has been recorded from southern California since the inception of environmental monitoring programs in the late 1960's, the effects of effluent discharge on the prevalence of *P. cincinnatus* have not previously been determined. Because stress factors resulting from changes in temperature, salinity, dissolved oxygen content, and pollutant exposure can affect the resistance of fish to disease and parasitic infection, we examined the prevalence of *P. cincinnatus* relative to season and proximity to effluent outfall sites. Sanddabs are relatively sedentary, are in contact with the sediment, and, off the coast of southern California, inhabit areas subject to environmental perturbations including pollution and anthropogenic interactions. Furthermore, the mesoparasitic mode of adult *P. cincinnatus* renders them easily visible without dissection and prevents them from becoming accidentally dislodged during collection. Therefore, another objective of this study was to evaluate the usefulness of the *P. cincinnatus-C. sordidus* relationship as a biological indicator of water quality.

Materials and Methods

Pacific sanddabs were collected from off Los Angeles (Santa Monica Bay and the Palos Verdes shelf), and off Point Loma, San Diego, in conjunction with the environmental monitoring divisions of the wastewater treatment plants of these cities. These monitoring programs are conducted in compliance with the National Pollutant Discharge Elimination System (NPDES) and include characterization of chemical and physical parameters of influent and effluent waters, and assessment of changes in the marine environment which could be attributable to effluent discharges from the plants. The data used to calculate the prevalence of *P. cincinnatus* were obtained from the field records of the Hyperion (City of Los Angeles), White Point (Los Angeles County), and Point Loma (San Diego) Treatment Plants. At each locality, Pacific sanddabs were collected using a 7.6 m otter trawl with a cod-end mesh of 1.3 cm, towed at 1 m/sec.

To determine if infection with the parasite affects the size of the host, standard length (SL) and weight of infected and uninfected Pacific sanddabs were measured. The sanddabs used for this assessment were collected in a single otter trawl in which about 10% of the fish were infected. This trawl was conducted off Point Loma in February, 1994 by Dr. Richard H. Rosenblatt of Scripps Institution of Oceanography.

Four Pacific sanddabs (three uninfected and one with a monocular infection of *P. cincinnatus*) were caught with hook and line from Monterey Bay, California. The fish were shipped to Scripps Institution of Oceanography where they were

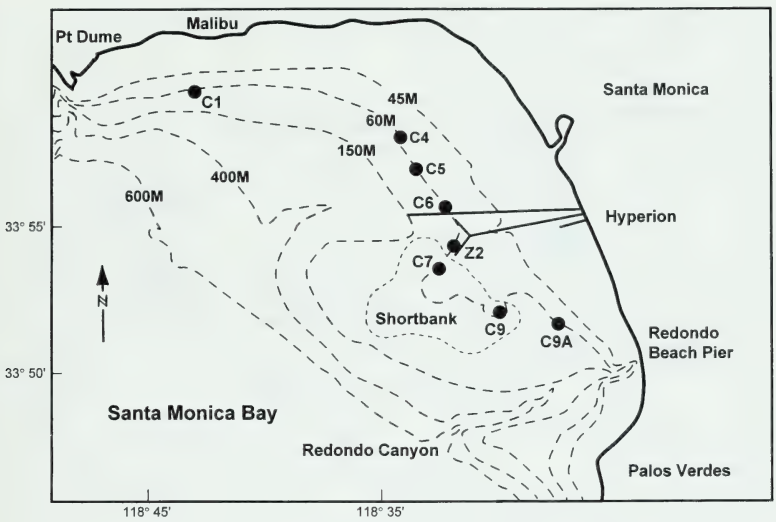

Fig. 1. Epibenthic trawl stations in Santa Monica Bay, Los Angeles, California. Modified from Dorsey (1992), City of Los Angeles.

maintained in an aquarium equipped with air and chilled running seawater. The fish were fed squid and shrimp.

According to the ecological terminology of Margolis et al. (1982), prevalence was expressed as a percentage and calculated as the number of infected hosts divided by the total number of hosts examined.

Santa Monica Bay, Los Angeles

Bordered by Point Dume to the northwest and Palos Verdes Peninsula to the south, Santa Monica Bay is located west of the Los Angeles metropolitan area (Fig. 1). It embodies an area of approximately 453 km^2, and contains two submarine canyons, two small craft marinas, and receives effluents from 64 storm drains. Treated sewage effluents are released directly into the Bay from either Hyperion or from Los Angeles County's Joint Water Pollution Control Plant. Approximately 22.7–30.3 $\times$ 10^6 L/day of treated petrochemical wastes, and thermal discharges from three power generating stations are discharged into the Bay (Dorsey 1992).

Pacific sanddabs were collected along the 60 m isobath which corresponds to the discharge depth of the Y-shaped, 5-mile outfall (Fig. 1). Samples were taken at fixed trawl sites on a quarterly basis. Prevalence data were compiled from trawls taken between 1989–1994.

White Point, Palos Verdes Shelf (Los Angeles County)

The monitoring area off of Palos Verdes (Fig. 2) is a physically and biologically diverse region. It includes a coastal promontory and narrow shelf, a submarine canyon to the northwest, and the San Pedro sea valley to the southeast (Stull 1995). Approximately 1249 $\times$ 10^6 L/day of partial secondary treated wastewater is discharged at a depth of 60 m through a pipeline that extends about 3 km offshore from White Point (Stull 1995). Quarterly samples were taken at 12 trawl

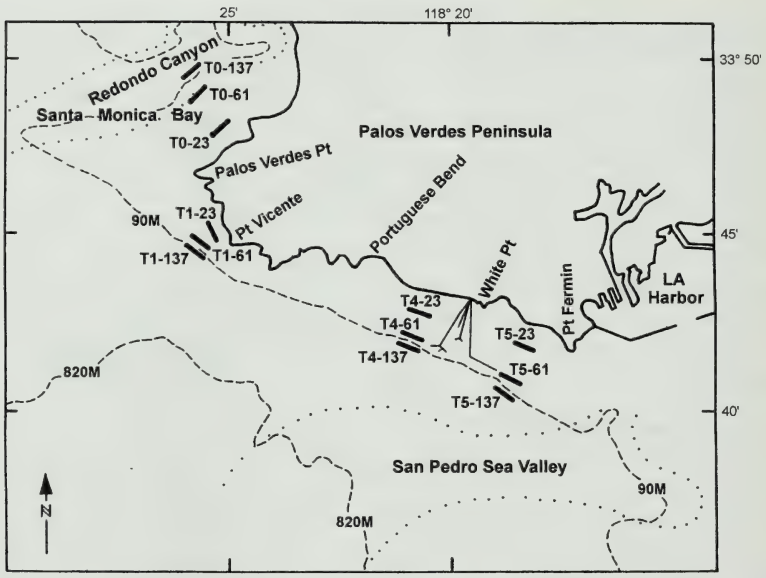

Fig. 2. Epibenthic trawl stations on the Palos Verdes Shelf, Los Angeles, California. Modified from a map provided by the Los Angeles County Sanitation Districts.

stations (Fig. 2). Prevalence of *P. cincinnatus* was calculated from trawl catches made between 1979 and 1995.

Point Loma, San Diego

The study area (Fig. 3) embodies 104 km^2 extending from Imperial Beach in the south to Mission Beach in the north, and is located west of the San Diego metropolitan area. The northern aspect of the area receives marine vessel traffic from Mission Bay which harbors several small craft marinas. San Diego Bay is the major port for San Diego. It includes multiple small craft marinas as well as commercial and naval vessels. San Diego Bay opens into the study area slightly south of its central aspect. The area contains an extensive kelp bed, a dredged materials dump site (LA-5 in Fig. 3), and receives runoff from two rivers. The Point Loma Treatment Plant discharged primary treated sewage from 1963 through mid-1985 when the facility began advanced primary treatment (removal of at least 75% solids). Treated effluent was discharged approximately 3.2 km offshore from Point Loma at a depth of 67 m. In July of 1991, the City of San Diego's ocean monitoring program was expanded to include quarterly sampled stations. This expansion was in preparation for extension of the outfall pipe. In November of 1993, the new Y-shaped diffuser became operational. It extended to 7.2 km offshore with a discharge depth at 98 m. The sites of the trawl stations were established prior to the outfall extension, and sampling was conducted as part of the City's pre-discharge monitoring program. Thus, the stations where sanddabs were collected for this study were at the same locations before and after extension of the outfall. Pacific sanddabs were collected at stations along the 100 m isobath (Fig. 3). Prevalence of *P. cincinnatus* was calculated from samples taken between 1992–1995.

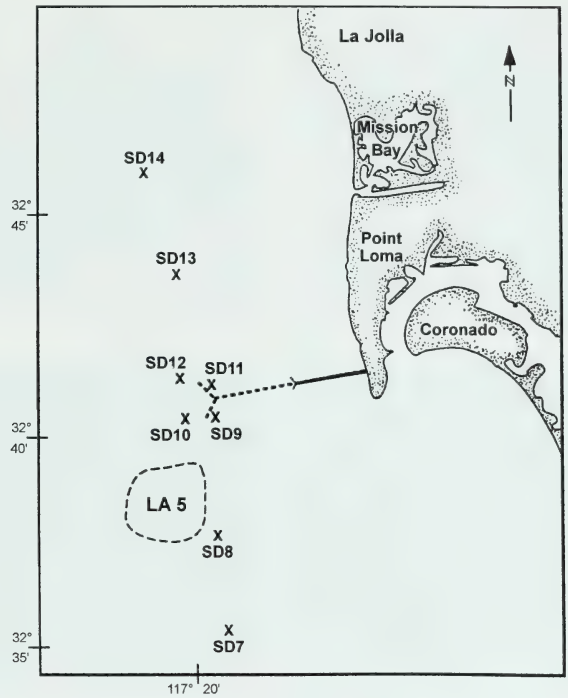

Fig. 3. Epibenthic trawl stations off Point Loma, San Diego, California. Dashed line represents the pipeline extension. Modified from a map by John Byrne (City of San Diego 1995).

Results

Host–Parasite Relationship

Specimens of *P. cincinnatus* infected Pacific sanddabs ranging in size from 4.5 to 24.0 cm standard length (SL). There was a positive correlation between the size of the host and the size of the parasite (Fig. 4A). Even small parasites infecting the eyes of newly settled sanddabs were able to attain sexual maturity. Most of the infected fish harbored a single parasite. The left eye was infected slightly more frequently (56.2%) than the right eye (43.8%). Multiple infections were uncommon; only four individuals of 232 infected fish had more than one adult parasite. One specimen, measuring 8.1 cm, harbored five parasites in its right eye (Fig. 4B). Infection of both eyes was extremely rare; only two specimens had a parasite in each eye (Fig. 4C).

Because monocular infections with *P. cincinnatus* were most common, we investigated the ability of a Pacific sanddab harboring a single parasite to survive the infection. Four sanddabs (three uninfected and one with a monocular infection) were caught by hook and line, and maintained in an aquarium at Scripps Institution of Oceanography for several months. The parasite was ovigerous at the time of capture, and exhibited no morphological changes for about six weeks. After the parasite shed all of its eggs, the body turned dark brown and disintegrated. Following the death of the parasite, the cornea of the infected eye became opaque (Fig. 4D); however, the fish was able to feed and survived for approximately three months after the parasite died.

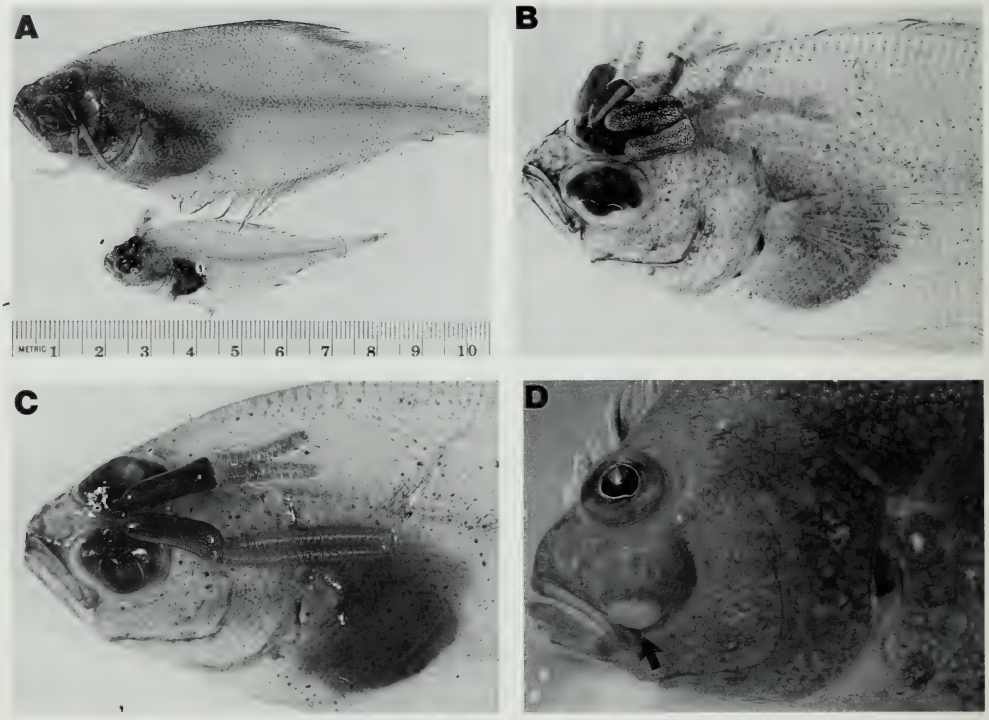

Fig. 4. Infection of Pacific sanddab (*Citharichthys sordidus*) with *Phrixocephalus cincinnatus*. A. Ovigerous *P. cincinnatus* infecting the eyes of two Pacific sanddabs of different sizes. Top specimen is 10.3 cm SL, bottom specimen is 5.1 cm SL. B. Pacific sanddab with five *P. cincinnatus* in right eye. C. Pacific sanddab with *P. cincinnatus* in both eyes. D. Photograph of a living, captive Pacific sanddab that survived monocular infection with a single *P. cincinnatus*. Opaque cornea, resulting after death and disintegration of the parasite, is denoted by an arrow.

We plotted the length versus weight of eight infected and 85 uninfected fish collected in a single trawl conducted by Scripps Institution of Oceanography, off Point Loma, San Diego. We found that infection with *P. cincinnatus* did not alter the length and weight of infected fish compared to controls (Fig. 5).

The total number of sanddabs captured in trawls off Point Loma (24,382 from 1992–95) was greater than that for Santa Monica Bay (10,096 from 1989–94), and the Palos Verdes shelf (20,749 from 1979–95). However, the fish were generally larger at either Los Angeles site compared to San Diego. Similarly, the most heavily infected sanddabs ranged in size from 7.1 to 12.0 cm in Santa Monica Bay (Table 1), 7.1 to 13.0 cm off Palos Verdes (Table 2), and from 5.1 to 11.0 cm off Point Loma (Table 3).

During the course of the study, ovigerous specimens of *P. cincinnatus* were found infecting several other species of fish. These were: (1) longfin sanddab (*Citharichthys xanthostigma*)—one specimen from Santa Monica Bay and two specimens from Point Loma; (2) pink seaperch (*Zalembius rosaceus*), collected off Point Loma at a depth of 100 m by Scripps Institution of Oceanography; (3) bay goby (*Lepidogobius lepidus*), collected from Santa Monica Bay at 100 m. In addition to harboring an ovigerous parasite, two post-mated juvenile female specimens were found within the globe of the eye of the bay goby. These represent

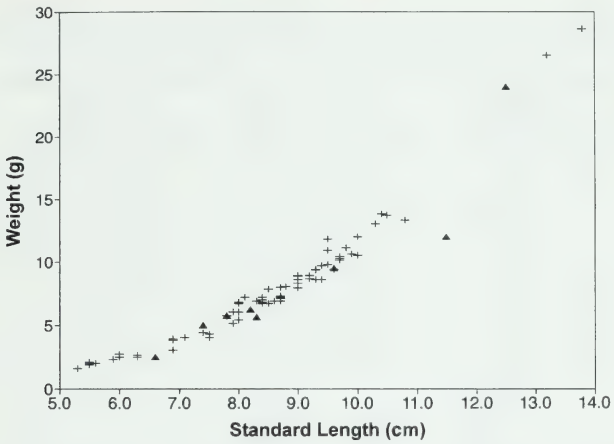

Fig. 5. Effect of *Phrixocephalus cincinnatus* infection on the length and weight of Pacific sanddab (*Citharichthys sordidus*). Sanddabs were collected in a single trawl off Point Loma, San Diego, California by Scripps Institution of Oceanography. Eight out of 85 specimens harbored the parasite.

Table 1. Prevalence of *Phrixocephalus cincinnatus* in Pacific sanddab, *Citharichthys sordidus* of various length-groups from Santa Monica Bay, Los Angeles, California, collected quarterly from 1989–1994.

Size class	Length-group (mm)	Number examined	Number infected	% infected
3	21–30	4	0	0
4	31–40	95	0	0
5	41–50	323	0	0
6	51–60	854	3	0.35
7	61–70	1169	5	0.43
8	71–80	1586	19	1.20
9	81–90	1589	29	1.82
10	91–100	1613	29	1.80
11	101–110	1132	13	1.14
12	111–120	892	15	1.68
13	121–130	442	8	1.80
14	131–140	215	1	0.46
15	141–150	76	4	5.26
16	151–160	38	3	7.90
17	161–170	18	0	0
18	171–180	16	0	0
19	181–190	8	0	0
20	191–200	13	1	7.7
21	201–210	4	3	75
22	211–220	4	1	25
23	221–230	2	1	50
24	231–240	1	0	0
25	241–250	1	0	0
26	251–260	1	0	0
Total		10,096	135	1.34

Table 2. Prevalence of *Phrixocephalus cincinnatus* in *Citharichthys sordidus* of various length-groups from Palos Verdes Shelf, Los Angeles, California, collected quarterly from 1979–1995.

Size class	Length-group (mm)	Number examined	Number infected	% infected
2	11–20	1	0	0
3	21–30	20	0	0
4	31–40	336	0	0
5	41–50	1089	0	0
6	51–60	1743	5	0.29
7	61–70	2012	33	1.64
8	71–80	2304	46	2.00
9	81–90	2114	55	2.60
10	91–100	1867	61	3.27
11	101–110	1857	46	2.48
12	111–120	1913	40	2.09
13	121–130	1788	40	2.24
14	131–140	1352	22	1.63
15	141–150	868	15	1.73
16	151–160	475	2	0.42
17	161–170	293	6	2.05
18	171–180	231	5	2.16
19	181–190	157	3	1.91
20	191–200	117	2	1.71
21	201–210	100	0	0
22	211–220	54	2	3.7
23	221–230	34	1	2.94
24	231–240	20	1	5.00
25	241–250	3	0	0
26	251–260	1	0	0
Total		20,749	385	1.86

the earliest developmental stages of *P. cincinnatus* ever reported. Although unconfirmed, the historical trawl data from San Diego reported *P. cincinnatus* infecting the Gulf sanddab (*Citharichthys fragilis*), California tonguefish (*Symphurus atricauda*), and California skate (*Raja inornata*). All of the above fish were new host records for *P. cincinnatus.*

Prevalence of P. cincinnatus *in Pacific Sanddab (*Citharichthys sordidus*)*

The overall prevalence of *P. cincinnatus* in Pacific sanddabs collected from Santa Monica Bay between 1989 and 1994 was 1.34% (135 infected fish out of 10,096 total specimens). During the six year study period, the prevalence varied by less than half a percent (1.05–1.36%). In 1995, the prevalence of *P. cincinnatus* increased to 1.69% (23 infected fish out of 1362 total fish). However, the location of some of the trawl stations was changed slightly. For example, station C3 replaced stations C4 and C5 because the transects of stations C5 and C6 overlapped (Deets and Roney 1994). Therefore, these data were not combined with the 1989–1994 data.

On the Palos Verdes shelf, overall prevalence between 1979 and 1995 was 1.86% (385 infected fish out of a total of 20,749 fish). However, infection with *P. cincinnatus* fluctuated from year to year. For example, the prevalence of *P.*

Table 3. Prevalence of *Phrixocephalus cincinnatus* in *Citharichthys sordidus* of various length-groups from Point Loma, San Diego, California, collected quarterly from 1992–1995.

Size class	Length-group (mm)	Number examined	Number infected	% infected
3	21–30	51	0	0
4	31–40	832	0	0
5	41–50	2555	6	0.23
6	51–60	3708	32	0.86
7	61–70	3914	52	1.33
8	71–80	3128	40	1.28
9	81–90	3568	33	0.92
10	91–100	3369	25	0.74
11	101–110	1658	19	1.14
12	111–120	860	7	0.81
13	121–130	453	4	0.88
14	131–140	185	0	0
15	141–150	65	0	0
16	151–160	34	0	0
17	161–170	19	0	0
18	171–180	14	0	0
19	181–190	7	0	0
20	191–200	0	0	0
21	201–210	0	0	0
22	211–220	1	0	0
Total		24,421	256	1.04

cincinnatus was as low as 0.31% (1 out of 322 infected fish) in 1984, and reached over 3% in 1980, 1982 and 1987 (Fig. 6).

Prior to 1995, prevalence of *P. cincinnatus* off Point Loma was only 0.54% (97 infected fish out of 18,009 total specimens), and varied little (0.47%–0.59%) between 1992–1994. However, in 1995, infection with *P. cincinnatus* increased dramatically to 1.90% (121 infected fish out of 6373) resulting in an overall prevalence of *P. cincinnatus* between 1992–1995 of 0.92% (221 infected fish out of 23,952 fish).

Because environmental monitoring was conducted on a quarterly basis, we were able to examine seasonal alterations in prevalence of the parasite (Fig. 7). Infec-

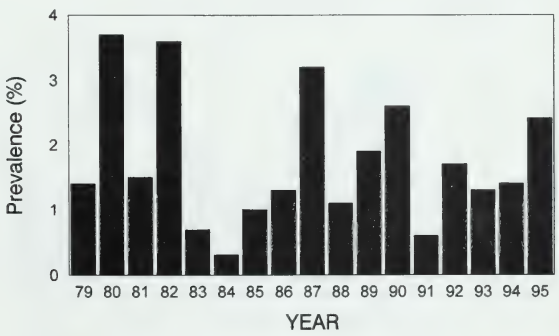

Fig. 6. Annual prevalence of *Phrixocephalus cincinnatus* in Pacific sanddab (*Citharichthys sordidus*) collected on the Palos Verdes shelf between 1979 and 1995.

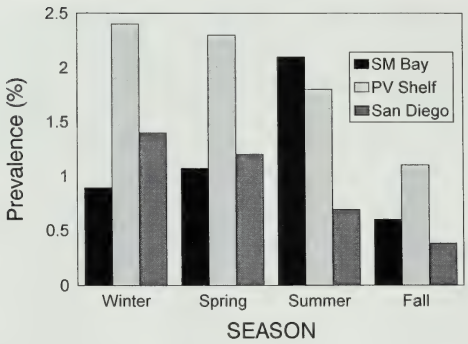

Fig. 7. Seasonal prevalence of *Phrixocephalus cincinnatus* collected from Santa Monica Bay, Palos Verdes shelf (Los Angeles), and Point Loma (San Diego), California.

tion of sanddabs from Santa Monica Bay was highest during the summer months (47 infected fish out of 2211), lowest in the fall (10 infected fish out of 1660), and increased slightly in the winter (32 infected fish out of 3572), and spring (37 infected fish out of 3458). Off Palos Verdes, infection was highest in the spring (108 infected fish out of 4221 fish) and winter (91 infected fish out of 3716 fish), dropped in the summer (109 infected fish out of 5630), and was lowest in the fall (81 infected fish out of 6957). Off Point Loma, the highest prevalence occurred in the winter (94 infected fish out of 6512) and spring (73 infected fish out of 5921), declined in the summer (31 infected fish out of 5780), and was lowest in the fall (28 infected fish out of 7386). In addition, the seasonal patterns of infection varied from year to year. Seasonal prevalence of *P. cincinnatus* from Palos Verdes (Fig. 8) and San Diego (Fig. 9) varied greatly between different years of the study.

To determine if effluent released from sewage treatment plants affected infection of sanddabs with the parasite, prevalence was calculated for at least six trawl sites situated at various distances from the effluent discharge pipeline in all three localities. The relative prevalence of *P. cincinnatus* along the 60 m isobath in Santa Monica Bay varied from north to south and with distance from the outfall (Fig. 10). Stations Z2 and C6, which are located closest to the pipeline, exhibited the highest levels of infection (2.60% and 1.80%, respectively), whereas C1

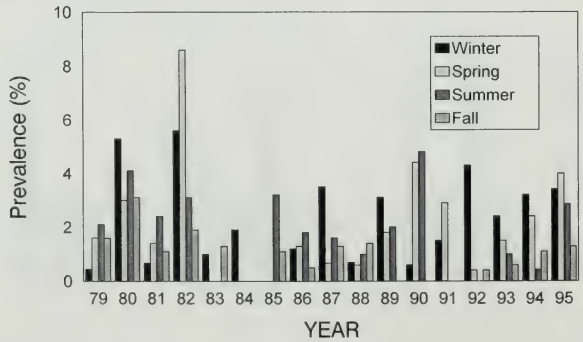

Fig. 8. Seasonal prevalence of *Phrixocephalus cincinnatus* collected from the Palos Verdes shelf, Los Angeles, California, between 1979 and 1995.

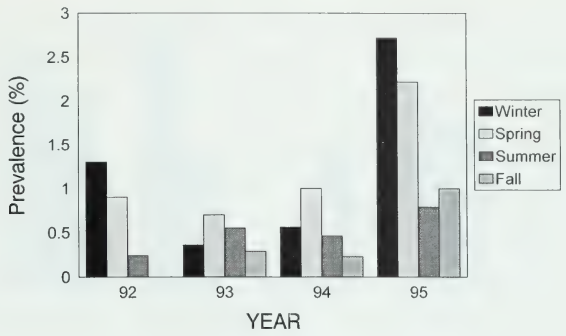

Fig. 9. Seasonal prevalence of *Phrixocephalus cincinnatus* collected from Point Loma, San Diego, California, between 1992 and 1995.

(1.0%) in the north bay and C9A (0.51%) to the south presented the lowest prevalence values. In 1995, prevalence at Z2 and C6 remained about the same (2.60% and 1.30%, respectively). However, station C3, which replaced stations C4 and C5, exhibited the highest prevalence (3.40%) of any of the stations. This was attributable to an increase in prevalence that occurred primarily during the summer quarter (5.29%). Prevalence at stations C1 and C9A dropped from previous years (0.63% and 0.35%, respectively).

On the Palos Verdes shelf (Fig. 11), 2.88% and 2.63% of the sanddabs collected at stations T4-137 and T5-137 were infected with *P. cincinnatus,* respectively. About 2% of the sanddabs collected at stations T5-61, T0-61, and T0-137 were infected, and roughly 1.5% of the sanddabs at stations T1-61 and T4-61 harbored the parasite. Station T1-137 had the lowest prevalence (0.5%).

In San Diego prior to 1995, station SD-13, located approximately midway between the discharge site and the northernmost station, demonstrated the highest prevalence (0.77%). SD-12, positioned offshore to the north leg of the Y-shaped discharge pipe, showed a prevalence of 0.70%. The lowest prevalences occurred at SD-14 (0.35%) and SD-7 (0.34%), the most northern and southern stations from the outfall site. However, in 1995 the distribution and prevalence of *P. cincinnatus* changed dramatically (Fig. 12). Clearly, the prevalence of *P. cincinnatus* was highest at all stations in 1995 compared to previous years. In addition,

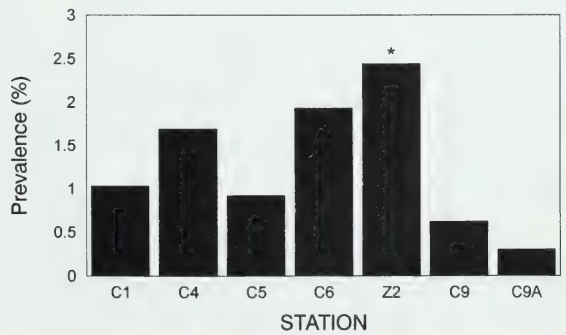

Fig. 10. Prevalence of *Phrixocephalus cincinnatus* at trawl stations in Santa Monica Bay, Los Angeles, California, from 1989 to 1994 combined. An asterisk denotes the station nearest to the outfall.

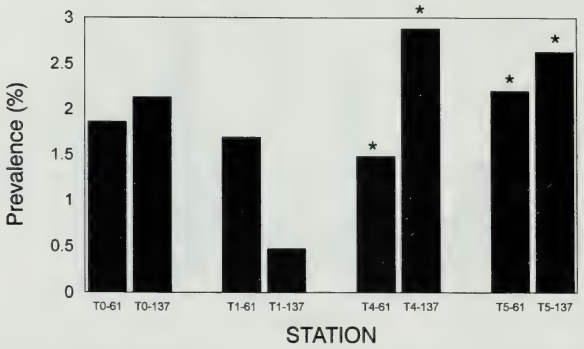

Fig. 11. Prevalence of *Phrixocephalus cincinnatus* at trawl stations on the Palos Verdes shelf, Los Angeles, California, from 1979 to 1995 combined. Asterisks denote the stations nearest to the outfall.

prevalence at SD-7 increased over seven-fold. SD-11 exhibited the highest level of infection, followed by SD-10 and SD-12. SD-8 was the only station where the prevalence of *P. cincinnatus* remained under 1%.

Discussion

Phrixocephalus cincinnatus has been reported reliably from only two hosts. It was described originally infecting Pacific sanddab in Monterey Bay, California. However, *P. cincinnatus* is a common parasite of the arrowtooth flounder, *Atheresthes stomias* Jordan and Gilbert, 1880 in Barkley Sound, British Columbia, Canada. For example, of a sample of 64 fish, 53 (82.8%) were infected with the parasite (Kabata 1969). In a subsequent report, Kabata and Forrester (1974) observed that *P. cincinnatus* did not uniformally infect the host population. Instead, the smaller length groups were most heavily infected, and the parasite population decreased with increasing host length and age, as well as depth.

In the present study, the overall prevalence of *P. cincinnatus* infecting Pacific sanddab was only about 1.4%. However, our data were compiled from over 55,000 fish collected from a much broader geographic range. The most abundant and commonly infected sanddabs ranged in size 5.1 to 12.0 cm, and *P. cincinnatus* was able to adjust its size in proportion to that of its host. The sanddabs from the Los Angeles areas are slightly larger than those from San Diego. Sanddabs

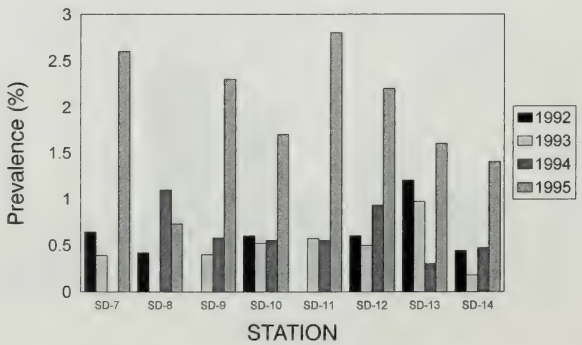

Fig. 12. Annual prevalence of *Phrixocephalus cincinnatus* at trawl stations off Point Loma, San Diego, California, between 1992 and 1995.

as big as 24 cm were infected, however sanddabs larger than 14 cm are uncommon off southern California. This is in contrast to arrowtooth flounder in which the smallest size class infected with *P. cincinnatus* was 16–20 cm (Kabata and Forrester 1974).

Kabata (1969) reported that 66% of the infected arrowtooth flounder harbored parasites in the right (lower) eye only, 5.7% had parasites in the left eye only, and 28.3% were infected in both eyes. The right eye of arrowtooth flounder is elevated and is located in the center of the head. Also, the left eye of the arrowtooth flounder is on the margin of the head next to the sediment and is less accessible to copepod larvae from the water column (M.J. Allen So. Calif. Coastal Res. Proj., Westminister, CA, personal communication). Kabata (1969) postulated that the free-swimming infective stage of *P. cincinnatus* encounters the elevated right eye of arrowtooth flounder with greater frequency then the left. Although Pacific sanddab is left-eyed, we found only a slight preference for the left eye by the parasite. This may be because the left (lower) eye is anterior to the right (upper) eye, but both eyes are nearly level and are on the upper side of the head.

Infection of either species of flatfish with *P. cincinnatus* results in the formation of a large hematoma in the choroid layer (Kabata 1969; Perkins 1994) without causing significant damage to the lens, cornea or retina of the eyes of fish harboring living parasites. As in arrowtooth flounder (Kabata 1969), the visual axis of infected Pacific sanddab is disrupted due to the expansion of the choroid layer, and occasionally, rotation of the eye caused by the weight of large parasites.

In captivity, Pacific sanddab survived monocular infection with *P. cincinnatus*. While the parasite was alive, the cornea remained clear. However, after death of the parasite, the cornea became cloudy and the fish was functionally blind in that eye. Kabata (personal communication) suggests that infected eyes may also be blind even if the cornea is clear. However, the fish retina is comprised predominately of rods and responds mainly to movement. Therefore, even if the visual axis is disrupted or part of the retina is destroyed by the parasite, the fish may still be able to detect prey and predators with the infected eye as long as the cornea is clear.

In Canadian inshore waters, where approximately 50% of the arrowtooth flounder were infected, only 1.5% of the fish possessed damaged eyes. Although no quantitative measurements were made, Pacific sanddab with opaque corneas were rarely encountered in otter trawl catches made off southern California. These results suggest that, in the wild, infected fish succumb to *P. cincinnatus*. Apparently, fish with monocular infections are able to feed and can survive as long as the parasite is alive and the cornea is clear. After the parasite dies, inflammation and osmotic imbalance across the cornea result in blindness rendering the fish less capable of feeding and/or avoiding predators. Because of the low level of infection (about 1.4%) off southern California, it is unlikely that mortality caused by *P. cincinnatus* significantly affects the host population.

Although some species of pennellids are known to alter the growth rate of their hosts (Kabata 1970; Van Den Broek 1978), Kabata and Forrester (1974) suggested that destruction of one eye had no immediate effect on the fish since there were no qualitative differences in the composition of the gut contents of fish with one infected eye compared to uninfected fish. Indeed, we found no difference in the

length and weight of infected sanddabs compared to uninfected fish caught in the same trawl.

During the course of this study, we observed differences and fluctuations in the prevalence of *P. cincinnatus* with respect to locality, season, annual abundance, and proximity to outfall sites. It is difficult to determine with certainty the causes for the alterations owing to the complexity of environmental, geographic and climatic factors occurring in the study regions. In addition, the life cycle of the parasite is unknown which further complicates analysis. For example, pennellids may have direct (larval development occurring in the water) or indirect (requiring an intermediate host) life history strategies. Consequently, an increase in prevalence of the adult parasite could be due to an increased abundance of a suitable intermediate host. Furthermore, the life span of the parasite, including its early developmental stages spent either on an intermediate host or in the plankton, is unknown. It was estimated by Kabata (1958) that the life span of adult *Lernaeocera branchialis,* a related species of pennellid infecting Atlantic cod, *Gadus morhua,* can vary from 2.5 months to 1.5 years. Khan (1988) determined that adult *L. branchialis* infecting captive Atlantic cod lived for about one year. Thus, the entire life cycle of *P. cincinnatus* could be as long as 1.5 years, and multiple broods could be produced by a single female. The decline in prevalance in the fall may reflect the end of the breeding season and death of the older parasites. Alternatively, physical oceanographic parameters, such as suitable substrata or currents, may directly affect the ability of larvae to find and attach to a host. According to Kennedy (1975), the population structure of parasites that utilize intermediate hosts is unstable because the probability of contact with an appropriate host is largely influenced by climatic or ecological factors.

In Santa Monica Bay and off San Diego prior to 1995, the prevalence of *P. cincinnatus* from year to year was relatively stable. However, on the Palos Verdes shelf, the prevalence of *P. cincinnatus* fluctuated annually, with peaks occurring in 1980, 1982, 1987, 1990, and 1995. El Niños occurred in 1978, 1982 to 1983, 1986 to 1987, 1991 to 1992. The ridgeback rock shrimp, *Sicyonia ingentis,* was very abundant from 1983–86 at T0-137 and T5-137 following an El Niño event. Similarly, the pelagic red crab, *Pleuroncodes planipes,* associated with El Niños, was abundant in 1984 and 1985 especially at T4-137 (Stull 1995). Coincidently, these stations had the highest overall prevalence of *P. cincinnatus.* Because the life span of the parasite may be as long as 1.5 years, there may exist a relationship between the abundance of *P. cincinnatus* and El Niño. Perhaps changes in water temperature and salinity affected the length of time required for the parasite to complete its life cycle, rate of egg maturation, or the reproductive capacity of the parasite. Alternatively, the pelagic red crabs that occur with El Niño, as well as ridgeback rock shrimp, may serve as incidental intermediate hosts.

The most dramatic change in the annual prevalence of *P. cincinnatus* occurred off of San Diego in 1995, when infection of sanddabs with the parasite increased 3.5-fold. Although the cause of this abrupt increase is unknown, two major events occurred off San Diego in 1993 which may have influenced the prevalence of *P. cincinnatus.* One event was the 1992–93 El Niño, and the concurrent appearance of numerous pelagic red crabs at the outfall extension. As previously mentioned, changes in physical and chemical oceanographic parameters, or immigration of suitable intermediate host(s) could be responsible for the observed increase. The

other event was the operation of the Point Loma outfall extension beginning in November of 1993. The two mile extension increased the approximate depth of discharge from 67 to 98 m, and delivered effluent close to several stations (SD-9 to SD-12) surrounding the outfall extension. Sampling at these stations began in 1991 as part of a predischarge monitoring program. According to the receiving waters monitoring report of the City of San Diego (1994), after one year of discharge, both the epibenthic macroinvertebrates and fish communities were not influenced by proximity to the outfall. In addition, they did not observe any pathologies indicative of environmental contamination, and there were few changes in sediment chemistry. The minor changes that occurred in benthic assemblages nearest the outfall were similar in composition to the natural communities of the area. However, the report suggested that it may be too soon to detect any major effects of the outfall on the local marine benthos. In 1994, levels of coliform bacteria decreased at the inshore, shallow water stations, and increased at stations located at depths of 78 m and greater corresponding to the relocation of the outfall diffusers (City of San Diego 1994). Possibly, the coliform bacteria provided a nutritive source for other organisms that resulted eventually in an increase in the abundance of an appropriate intermediate host. By 1995, one year following the operation of the pipeline extension, changes in sediment composition were observed. Between 1994 and 1995, there was an increase in the percentage of sand comprising the sediment at the deepwater stations, particularly at E 14 which is located nearest to the discharge zone (City of San Diego 1995). The changes in sediment may have favored the survival and transmission of parasite larvae. The fact that prevalence increased in 1995 at all stations except SD-8, suggests that a large scale oceanographic event, rather than operation of the outfall extension, was probably responsible for the observed increase.

In Santa Monica Bay, there appears to be a correlation between proximity to effluent discharge sites and higher prevalence of *P. cincinnatus.* Similarly, on the Palos Verdes shelf, stations at T4 and T5 collectively had the highest prevalence, and are located closest to discharge sites. Conversely, stations T1-61 and 137 combined exhibited the lowest prevalence, and are approximately 7.4 km north of the pipeline. Interestingly, T0, located in Santa Monica Bay and to the north of Palos Verdes Point, displayed a slightly higher combined prevalence compared to the T1 stations suggesting that factors other than distance from outfall sites may be more important determinants of infection with the eye parasite at this station.

Mearns and Sherwood (1977) described the prevalence of *P. cincinnatus* in Pacific sanddabs collected from southern California between 1974 and 1975. They reported that the prevalence of *P. cincinnatus* increased with distance from the Palos Verdes shelf. Of over 1000 Pacific sanddabs collected from Palos Verdes shelf, none were infected with the parasite. Mearns and Sherwood (1977) suggested that elevated levels of chlorinated hydrocarbons in the tissues of the fish from Palos Verdes shelf may be responsible for the lack of infection. Because *P. cincinnatus* is a naturally occurring parasite, its disappearance could indicate poor water quality. Contaminated water could affect the adult parasite directly because it ingests host blood, or polluted water might eliminate the parasite's intermediate host. However, it is unclear whether chlorinated hydrocarbon levels were measured from the sanddabs or from other fish species captured on the shelf. In

addition, their collection(s) were made over the course of a year. Our data show that the parasite has been present continuously on the Palos Verdes shelf from 1979 to 1995, and that prevalence fluctuates seasonally as well as from year to year. For example, in 1984 infected Pacific sanddabs were collected only in the winter trawls, whereas in 1985, no infected fish were collected in the winter. The trawls that Mearns and Sherwood (1977) examined may have missed the infected fish. According to Stull (1995), the variability of the region is a major factor influencing the abundance, distribution and succession of the organisms in the area, and makes it difficult to differentiate between natural events and effects of discharged effluent.

In San Diego, the stations with the overall highest prevalence were SD-9 to SD-13. With the exception of SD-13, these stations surround the Y-shaped outlet. Presuming that there is a correlation between effluent outfall and prevalence of the parasite off San Diego, currents flowing northward could disperse wastewater discharged from the outfall site to SD-13. In 1995, SD-7, which is located far to the south of the outfall, exhibited the second highest level of prevalence, and station SD-8 exhibited the lowest. These results suggest that environmental factors may play a predominant role in determining the prevalence of *P. cincinnatus*. The low prevalence at SD-8 may be related to the elevated levels of heavy metals originating from the dredged materials dump site (LA-5).

Although three other species of sanddabs belonging to genus *Citharichthys* (longfin sanddab, gulf sanddab, and speckled sanddab, *C. stigmaeus*) are also found in southern California, *P. cincinnatus* rarely infects these species. In fact, only two specimens of longfin sanddab were found carrying *P. cincinnatus*. Therefore, it is interesting that *P. cincinnatus* commonly parasitizes flatfish belonging to two different families (Pacific sanddab in the Paralichthyidae, and arrowtooth flounder in the Pleuronectidae), but does not ordinarily infect other members of genus *Citharichthys*. Species preference could be related to the distribution and feeding behavior of Pacific sanddab and arrowtooth flounder. Pacific sanddab (in the south) and arrowtooth flounder (in the north) are among the most abundant flatfishes in the middle shelf zone (20–100 m), and both species feed mainly on euphausids (M.J. Allen, So. Calif. Coastal Water Res. Proj., Westminster, CA, personal communication).

In terms of species associations, Pacific sanddab is found with Dover sole (*Microstomus pacificus*); English sole (*Pleuronectes vetulus*); plainfin midshipman (*Porichthys notatus*); stripetail rock fish (*Sebastes saxicola*); yellowchin sculpin (*Icelinus quadriseriatus*); pink seaperch, and shortspine combfish (*Zaniolepis frenata*) (cf. Allen 1982). Of these fish, a single specimen of pink seaperch was found infected with an ovigerous *P. cincinnatus*. Furthermore, a bay goby was also found harboring an ovigerous adult and two juvenile stages of *P. cincinnatus*. These incidental infections may be attributable to overlap in host distribution as well as similarities in behavior. It also suggests that *P. cincinnatus* is not, at least from a biochemical standpoint, very host specific.

In conclusion, we examined the yearly and seasonal prevalence of *P. cincinnatus* in Pacific sanddab. In addition, we examined prevalence with respect to distance from wastewater outfall sites of three southern California sewage treatment plants. Although there appears to be a correlation between distance from outfall sites and prevalence of *P. cincinnatus,* the overall level of infection of

sanddabs is low. It is difficult to assess the usefulness of *P. cincinnatus* as an indicator of water quality because the prevalence prior to discharge is unknown. Furthermore, erratic currents in these areas are capable of dispersing wastewater at distances up to 17 km from the outfall (Dalkey and Shisko 1996). An increase in prevalence of *P. cincinnatus* could reflect two completely different situations. First, it could indicate decreased resistance of the fish to parasitic infection as a result of declining water quality. Conversely, an increased prevalence could indicate an improvement of water quality resulting in the recruitment of intermediate hosts, and/or less toxicity to the adult parasite. Most of the observed alterations in prevalence of *P. cincinnatus* were probably the result of natural environmental fluctuations. Because the quarterly monitoring program off San Diego began relatively recently, there are no long-term prevalence data for *P. cincinnatus.* Therefore, continued monitoring off San Diego is necessary to elucidate the causes underlying the abrupt increase in prevalence of *P. cincinnatus* seen in 1995.

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First Record of the Crab *Pilumnoides rotundus* Garth (Crustacea, Decapoda, Brachyura, Xanthidae *sensu lato*) from Off Southern California

Joel W. Martin[1] and Ronald G. Velarde[2]

[1]*Natural History Museum of Los Angeles County, 900 Exposition Boulevard, Los Angeles, California 90007*
[2]*City of San Diego Marine Biology Laboratory, Ocean Monitoring Program, 4918 North Harbor Drive, Suite 101, San Diego, California 92106*

The xanthid crab genus *Pilumnoides* Lucas, 1844 (in Milne Edwards and Lucas 1844) includes eight species of mostly tropical crabs, four of which occur in the Americas (Guinot and MacPherson 1987). Only two species are known from the Pacific: *P. perlatus* (Poeppig, 1836), which ranges from Panama south to Peru and Chile, and *P. rotundus* Garth, 1940, which was originally described from seven specimens collected from two different islands in the Gulf of California and from Bahia San Francisquito on the eastern coast of the Baja California peninsula, Mexico (Garth 1940: 84–86, pl. 23, figs. 1–5). Since that time (Garth 1940), *P. rotundus* has been mentioned only rarely, and all range extensions save one have been to the south (see species synonymy below and also Guinot and MacPherson 1987: 231). The sole northern extension was to Cedros Island on the west coast of Baja California, Mexico, a site listed by Hendrickx (1995) as "unpubl. data" (see Discussion).

In this paper, we report *Pilumnoides rotundus* Garth for the first time from southern California (off San Diego). This extends the known range approximately 660 km northward from Bahia San Francisquito, Mexico, and over 1354 km northward measured from Cabo San Lucas at the southern extremity of the Baja California peninsula (assuming that the species extends that far south within the Gulf of California). Assuming that the unpublished Cedros Island, Mexico, record mentioned by Hendrickx (1995: 138) is valid, that site still lies some 530 km south of our collecting site. The new locality is the northern record for the genus in the Pacific.

Materials and Methods

The single male specimen was collected on 13 July 1994 at a depth of 69.5 m from the ship *Monitor III* at SDFT (San Diego Fish Trawl) station 1769, off the coast of San Diego, California, between La Jolla and Pacific Beach, an area encompassed by the San Diego River to the south and the La Jolla Submarine Canyon to the north. The collection resulted from a 10-min. otter trawl centered on latitude 32°48.05′N, longitude 117°19.60′W. Because the specimen was collected during a trawl, exact microhabitat and substrate conditions are not known. Fathometer readings on an initial pass, during which the trawl was not deployed (in order to lessen the risk of losing the trawl), indicated a sharp drop in depth at one point, such that some structure was likely present near to the area where the crab was collected. Trawl observations for that station included noting that

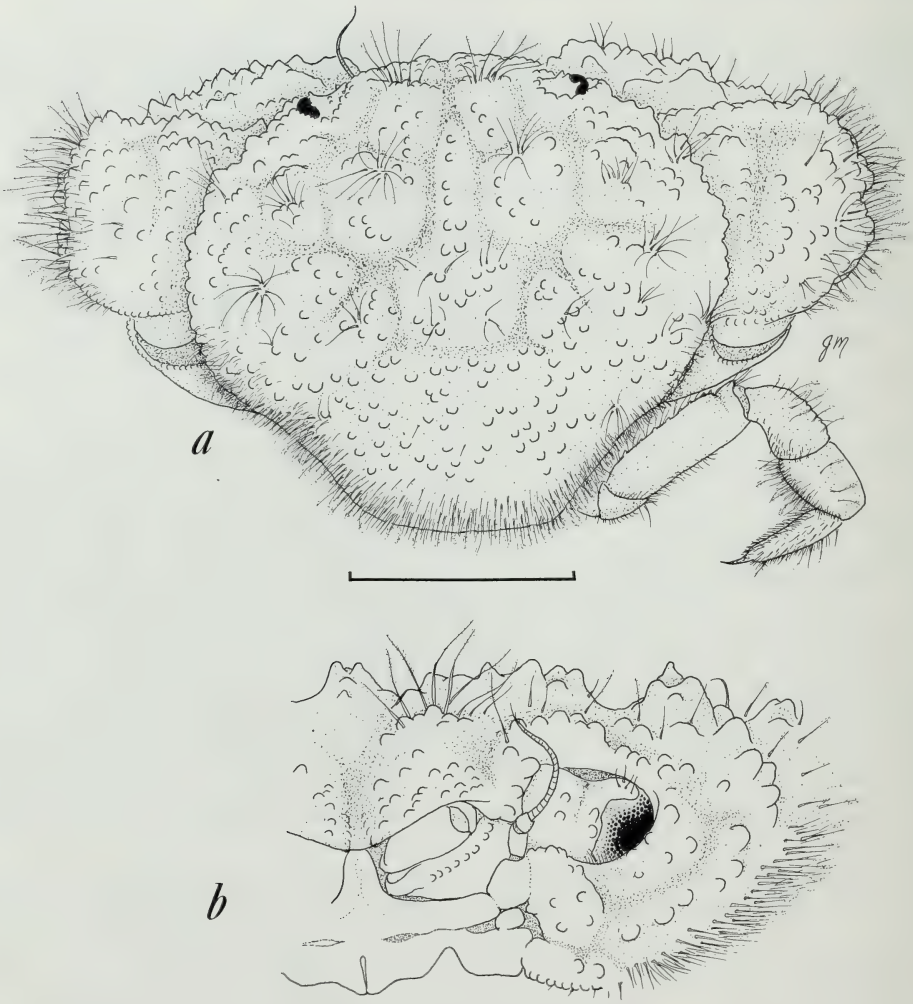

Fig. 1. *Pilumnoides rotundus* Garth, male collected off San Diego, California (LACM 94–94.1). a, dorsal view of carapace, chelipeds, and right third walking leg. b, frontal view of left orbital region. Scale bar = 5.0 mm for Fig. a only.

the brown alga genus *Laminaria* was present. Illustrations were completed using a Wild M5APO dissecting stereomicroscope with attached camera lucida. The specimen (originally Southern California Bight Pilot Project [SCBPP] voucher specimen number C-8; now LACM 94-94.1) has been deposited in the Crustacea collections of the Natural History Museum of Los Angeles County. Comparisons were made with Garth's (1940) original type series.

Pilumnoides rotundus Garth, 1940
(Figs. 1–3)

Pilumnoides rotundus Garth 1940: 84, pl. 23, fig. 1–5 [Gulf of California and Baja California, Mexico].—Del Solar and Alamo 1970: 3 [Banco de Mancora, Peru].—Del Solar et al. 1970: 33 [Peru].—Fonseca 1970: 55 [Peru] (list).—Guinot and MacPherson 1987: 231, Fig. 4H, 6C–D; pl. I, J–L.—Hendrickx

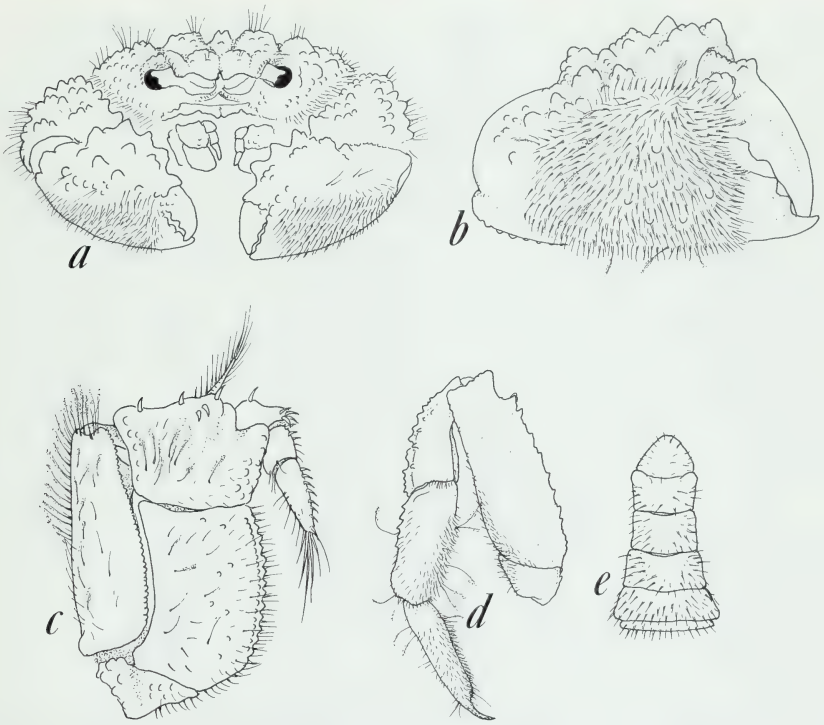

Fig. 2. *Pilumnoides rotundus* Garth, male collected off San Diego, California. a, frontal view of chelipeds in situ. b, frontal view of right chela, tilted more upright than as seen in fig. a. c, right third maxilliped, outer view. d, left second walking leg, ventral (functionally dorsal) view. e, abdomen in situ (basal two somites obscured because of curve of cephalothorax).

1992: 7 [Gulf of California, Mexico] (list).—Hendrickx 1993:313 [Mexico] (list).—Hendrickx 1995: 138 [Cedros Island, western coast of Baja California, Mexico] (list).

Material examined.—LACM 94–94.1, male, California, off San Diego, between La Jolla and Pacific Beach, latitude 32°48.05′N, longitude 117°19.60′W, 69.5 m, coll. 13 July 1994, 69.5 m, SDFT station 1769. LACM 37–132.1 (holotype, female, formerly AHF type number 374, Mexico, Gulf of California, San Esteban Island, *R/V Velero* Station 729–37, 35 fathoms [68 m], coll. 27 March 1937), and LACM 36–78.4 (allotype male, formerly AHF Type No. 374a, Mexico, Gulf of California, south end of Tiburon Island, *R/V Velero* Station 564–36, 8–10 fathoms [15–19 m], coll. 10 March 1936) examined for comparison. Size of San Diego specimen (LACM 94–94.1).—Carapace width 11.3 mm, carapace length 10.2 mm.

Comparison with Previous Illustrations

The species has been illustrated only twice previously, once when first described (Garth 1940) and again when the genus was revised by Guinot and MacPherson (1987). Our single male from off San Diego (Figs. 1–3) agrees in almost all respects with both of these studies, with the following exceptions.

Fig. 3. *Pilumnoides rotundus* Garth, male collected off San Diego, California. a, first pleopod, inner (left) and outer or posterior (right) views. b, higher magnification of tip of first pleopod. c, second pleopod, outer (posterior) view. d, higher magnification of tip of second pleopod. Scale bar = 1.0 mm for Figs. a, c.

Carapace: Garth's figure of the female holotype (Garth 1940: pl. 23, fig. 1), carapace length 7.4 mm, carapace width 8.8 mm (LACM 37–132.1; former AHF 374), has larger anterolateral teeth, and the overall impression is not as rounded as in the San Diego specimen (Fig. 1a). The carapace in the female paratype (USNM 78736, carapace width 8.3 mm) photographed by Guinot and MacPherson (1987: pl. 1, fig. K) is much closer to our Fig. 1a. Garth's figure of the carapace does not show the characteristic distally plumose setae found in clumps scattered over the anterior areolations of the carapace (Figs. 1a, b, 2a), and these are not visible in Guinot and MacPherson's photograph either. The fronto-orbital region of the carapace figured by Garth (1940: pl. 23, fig. 5) differs from that in our specimen (Figs. 1b, 2a) only in the detailed granulation of the epistome and in the setation (which Garth did not illustrate).

Chelipeds: Garth's dorsal view of the holotype (Garth 1940: pl. 23, fig. 1) agrees with ours (compare to Figs. 1a, 2a, b), but unfortunately Garth's figure of the frontal view of the chela of the holotype (Garth 1940, pl. 23, fig. 2) shows it with rather few short setae, thereby minimizing one of the most salient features of the species. Similarly, Guinot and MacPherson's photograph (1987: pl. 1, fig. L) of the chela of the female paratype (USNM 78736) seems to have been taken with the appendages out of water, such that the setae are matted. The overall appearance is therefore quite different from our figures (especially 2a, b), which were drawn with the specimen submerged to allow the setae to stand out.

Third maxillipeds: Garth's figure (1940: pl. 23, fig. 4) is similar in shape to that in our specimen (Fig. 2c), but does not show the small, clear, corneous spines arising from the distal borders of the carpus and merus.

Abdomen, ambulatory legs, pleopods: Garth's figure of the abdomen of the male allotype (Garth 1940: p. 23, fig. 3) agrees with our specimen (Fig. 2e), with the exception that our illustration shows a relatively shorter and slightly more triangular terminal article (possibly a result of the angle of the illustration) and lacks the dense fringing setae of this article depicted in Garth's figure. Neither Garth (1940) nor Guinot and MacPherson (1987) illustrated an individual ambulatory leg (our Fig. 2d), although Garth's written account agrees fully with our specimen. Guinot and MacPherson's figures of the first and second male pleopods (their figs. 6C–D) are in almost complete agreement with our own illustrations (Fig. 3); there are a few more distal setae on the first pleopod of our specimen (Figs. 3a, b) and the spines are illustrated with basal sockets (such that they articulate with the pleopod) in our Fig. 3b, vs. appearing fused to the cuticle of the pleopod in Guinot and MacPherson's (1987) fig. 6C.

Remarks.—Pilumnoides rotundus Garth is immediately recognizable and differs from any crab previously reported from California waters in having the following combination of characters: carapace almost completely circular (even more so than in *Cancer oregonensis*; see Nations 1975, fig. 30-1), deeply eroded, markedly granulate; chelipeds massive, with 3 or 4 large, nodulose teeth along dorsal border; ventral half of chelae with thick mat of distally plumose setae; distally plumose setae occurring also in clumps on carapace and scattered on other appendages; merus of ambulatory pereopods with sharply granulate dorsal border.

Additionally, according to Garth (1940: 85), the species exhibits the following colors when living: "Carapace dull ochraceous buff with varicolored granules, most chrome orange, some carmine red, and others bright cadmium orange. Ground color of chelae reed [sic] yellow with granular spines scarlet red. Fingers sayal brown. Merus of ambulatory legs yellowish cream buff with two broad bands of orange. Carpus and propodus orange red, dactylus white, touched with red at base." Our specimen was not closely examined until some time after preservation, when most of the coloration had faded.

Discussion

Habitat and Distribution

Garth (1940) briefly discussed the habitat of the original series as follows: 35 fathoms [68 m], shell (female holotype); 8–10 fathoms [15–19 m], kelp, coralline (male allotype); 165 fathoms [319 m], shale and mud (four paratypes), and 125 fathoms [242 m], shale, rock, and mud (ovigerous female paratype). Guinot and MacPherson (1987) reiterated this with only minor modifications ("10 a 300 m, sur fonds de coquillages, de roques, de vase, d'Algues"). Thus, specific habitat information is not available from previous collecting data. The single crab that forms the basis of our report was collected during a short benthic trawl over a variety of sediment types (see Materials and Methods); no details of specific habitat are available. The collecting depth of 69.5 m is well within the previously reported depth range (10 to 300 m) for the species.

The Cedros Island site mentioned by Hendrickx (1995) is based on observations

in letters to Hendrickx from J. Garth (M. Hendrickx, pers. comm.). These observations included reports of *P. rotundus* from Cedros Island, Natividad Island (27°55′N), and Dewey Canal (27°42′N), and are probably trustworthy (M. Hendrickx, pers. comm.).

This report marks the northern record of the genus in the Americas and, with the exception of *Pilumnoides inglei* Guinot and MacPherson in Great Britain, the northern record of the genus worldwide. Additionally, the specimen is the largest yet reported for this species.

Possible Mechanisms of Arrival in Southern California

Recent years have seen a number of typically tropical species occurring in southern California, and the finding of *Pilumnoides rotundus* may fit into this category. These observations have included sightings by Scripps Institution of Oceanography divers of the Cortez Angelfish (pers. comm.), the presence of at least one Central American shrimp species in local waters (Southern California Association of Marine Invertebrate Taxonomists, unpubl. data), and previously undescribed scyphozoans believed to have come from more southern waters (Martin and Kuck 1991). The Martin and Kuck (1991) report might also suggest the possibility of rafting via a scyphozoan host, although xanthids are not known to do this. Whether these occurrences are direct results of El Niño events are unclear. The 1982–1983 El Niño event was this century's strongest; one result was that the Pacific Equatorial Current reversed direction and extended eastward for 8000 miles to the coasts of North, Central and South America (Canby 1984). During or shortly after this El Niño event there were reports of barracudas off the coast of Oregon and tropical vertebrates and invertebrates along the western coasts of North and South America (Canby 1984; Wooster and Fluharty 1985; Martin and Kuck 1991).

Another possibility is that the species was carried northward as a larval stage in ballast waters (e.g., see Carlton 1985). The depth range of the species and the fact that its source of origin (the Gulf of California, Mexico) is relatively close may indicate that the species has always been present along the coast of southern California but has been previously overlooked. It is of interest that Hendrickx (1995) lists the species from Cedros Island, on the west coast of Baja California, Mexico, only as recently as 1995, such that a recent northward expansion may be indicated.

Acknowledgments

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The Euryhaline Cottid Fish, *Leptocottus armatus* Girard 1854, Second Intermediate Host of the Trematode, *Ascocotyle* (*Phagicola*) *diminuta* Stunkard and Haviland 1924

Mark Armitage

Azusa Pacific University, 587 Ventu Park Road, STE 304, Thousand Oaks, California 91320

Abstract.—*Ascocotyle diminuta* is reported from the gills of a new second intermediate host, *Leptocottus armatus* (the staghorn sculpin), collected at Point Mugu Naval Air Station, Point Mugu, California. Adult worms were not recovered from experimental hosts. A review of parasites previously described for the staghorn sculpin is presented.

Heterophyid trematodes of the genus *Ascocotyle* parasitize estuarine poeciliid, cyprinodontid and centrarchiid fishes as second intermediate hosts at the metacercarial stage of their life cycle. Prior to encystment in the fish, the trematode cercaria develops in hydrobiid snails which also inhabit the estuary. The life cycle is usually completed in the gastrointestinal tract of piscivorous birds which feed at the estuary. Metacercarial cyst location within the fish host is species dependent and typically includes the heart, liver, mesentary, muscle tissue, and/or the gills.

Many authors have labored for some seventy years to bring order to the classification of the *Ascocotyle/Phagicola* complex. Although the work has been detailed, much taxonomic confusion still remains within this group.

Maxon and Pequegnat (1949) report in their study of cercarial types at Newport Bay that the killifish, *Fundulus,* was found "to be heavily infected with many different kinds of metacercaria in the muscles, in the abdominal cavity and in the fins." No report of gill cysts was made although the current author has excysted *Ascocotyle* worms from *Fundulus parvipinnis* Girard and *Gambusia affinis* Baird and Girard collected at Newport Back Bay.

Stunkard and Uzman (1955) described *A.* (*Phagicola*) *diminuta* found encysted in the gill filaments of both *F. heteroclitus* and *F. majalis* collected at Milford, Connecticut. These authors regarded *Phagicola* to be a subgenus of *Ascocotyle* and provided a circumoral spine count of 16 (anterior row) + 2 (posterior dorsal row). Burton (1958) supplied no discussion of metacercarial host or cyst location but did provide a taxonomic key identifying *P. diminuta* with "18 circumoral spines or less (about 16)", and *P. langenformis* with 16 anterior spines and 2 posterior dorsals.

Hutton and Sogandares-Bernal (1960) described and illustrated *Parascocotyle diminuta* from the gills of *F. similis* and indicated the worm had 16 spines in an anterior row with 2 posterior dorsals. Later, Sogandares-Bernal and Lumsden (1963) treated *A. diminuta* and *A. nana* as junior synonyms of *A. angrense,* found in gill filaments of poecilliids and cyprinodonts with 16–18 spines anterior and 2–3 posterior.

Font et al. (1984B) described metacercarial cysts exclusively from centrarchids,

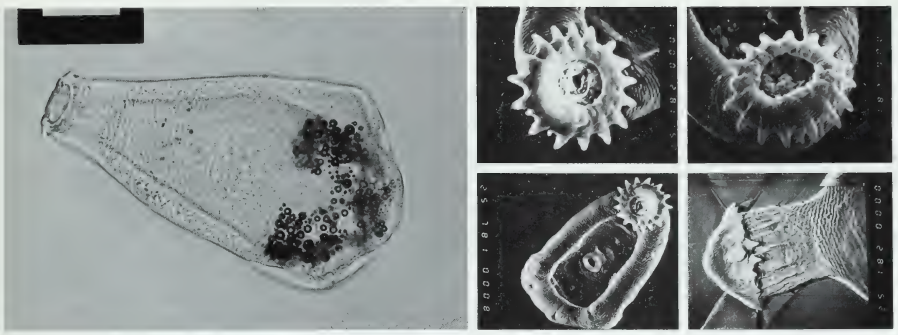

Fig. 1. *Ascocotyle diminuta,* excysted metacercaria, brightfield.
Fig. 2. *Ascocotyle diminuta,* excysted metacercaria, SEM.

found mostly in the body cavity and musculature with some mention of gill encystment. Gill cysts were found only in fishes that were heavily infected, and "Gills never contained abundant infections . . . ." They no longer regarded *P. nana* a synonym of *A. angrense* and report it with a 16 + 6 spine count. Although references were made to the herein previously mentioned work, the authors persisted in using the name *P. angrense,* and the circumoral spine count of adults recovered from a raccoon was given as 16 + 2. Finally, Ostrowski de Nunez (1993) resurrected *A.* (*P.*) *diminuta* (with a spine count of 18 + 2) from synonymy with *A.* (*P.*) *angrense* (16 + 2) and described cysts as being located in the gills of freshwater fishes. Whatever the terminology, it is clear that the *Ascocotyle* presented herein has a spine count of 16 + 2, and therefore is regarded as *A.* (*P.*) *diminuta.*

Several workers have studied the parasites of the Pacific staghorn sculpin, *Leptocottus armatus* Girard, but none has reported on the presence of *A.* (*P.*) *diminuta.* Lloyd (1938) found digenetic trematodes infecting *L. armatus* in the Puget Sound, but no ascocotylids were reported. Dunlap (1951) surveyed the parasites found in 100 staghorn sculpins but did not report any gill cysts or *Ascocotyle.* Jones (1962) made mention of the analysis of stomach contents of *Leptocottus* but no parasites were reported. Burreson (1973) also surveyed 560 sculpins for parasites and described 17 found but *Ascocotyle* was not reported. In addition, in

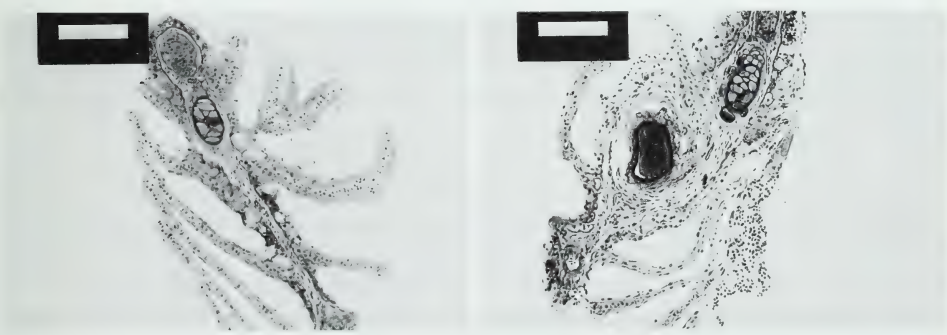

Fig. 3. *Leptocottus armatus,* uninfected gill.
Fig. 4. *Leptocottus armatus,* metacercaria encysted within gill.

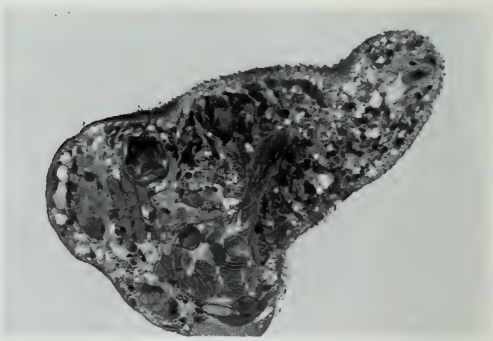

Fig. 5. *Ascocotyle diminuta,* worm section, brightfield.
Fig. 6. *Ascocotyle diminuta,* worm section, brightfield.

studies of *L. armatus* by Tasto (1975) and Armstrong (1994) no parasites were found encysted in the gills and no *Ascocotyle* was reported. Maxon and Pequegnat (1949) studied cercaria from the Newport Bay area, 90 mi south of Point Mugu and reported on pleurolophocerous cercaria which would correspond to *A.* (*P.*) *diminuta,* but state only that these cercaria resemble the description of *Cryptocotyle lingua* by Stunkard (1930).

To date most of the hosts described for the metacercarial stage of *Ascocotyle* (*Phagicola*) *diminuta* are brackish and fresh water fish which do not migrate into a highly saline environment (Saiki 1994) later in their life cycle development. In this paper, *A.* (*P.*) *diminuta* is reported from cottid fish in a predominantly marine environment.

Materials and Methods

One hundred *Leptocottus armatus armatus* specimens were collected by trap from the 12th Street bridge over the Mugu lagoon area of the Point Mugu Naval Air Station, California, from May 1996 through September 1996. The hearts, gills and livers of these fish were harvested and examined under a Carl Zeiss Stemi dissecting microscope for the presence of metacercarial cysts. No cysts were found in the hearts or livers. Additionally, 10 *Fundulus parvipinnis,* as well as 10 *Gambusia affinis* yielded heavy gill and liver infections while 4 longjawed mudsuckers (*Gillichthys mirabilis*) were inspected but no metacercaria were found. Gills from 25 sculpin, each with heavy cyst infection were fed to 2 day-old chicks over a 12 hr period. The chicks were examined after 24 hr for trematodes but no adults were recovered. Photomicrographs were taken of whole live material, of sections and of fixed, stained worms on a Carl Zeiss Axioskop microscope and on a Jeol JSM 35 scanning electron microscope.

Discussion

Unlike *Gambusia* and *Fundulus* which also inhabit Mugu lagoon, *Leptocottus* is a bottom dweller and bottom feeder, feeding mostly on polychaetes, shrimp and juvenile crabs (Armstrong et al. 1994; Burreson 1973; Dunlap 1951; laboratory aquaria observations). In addition, *L. armatus* has been shown to be very active at night and not as active during the day (Tasto 1975), which would make them available to immediate predation by *A.* (*P.*) *diminuta* when they are shed

by the first intermediate host during the daylight hours (Font et al. 1984A). This might explain the observation that almost every sculpin had at least some gill cysts and many had several hundreds. Heavily infected sculpins observed over a 4–6 week period in laboratory aquaria exhibited no respiratory stress and were less "jittery" than sculpins which later turned out to be lightly infected or uninfected. Of the sculpins which died during captivity, none had a heavy infection, while most of the heavily infected fish survived well, and even proved difficult to catch with a dip net. The excysted metacercaria were somewhat opaque and did not clear well enough in xylene for organ study, nor did they stain well in Van Cleave's Hematoxylin, but the organs show up well in sectioned worms, showing that the ceca do not descend past the testes and that the vitellaria are anterior to the testes. Gills were fed to 2 day old chicks, but no adults were recovered, however, the rectum was not autopsied, nor were other experimental hosts employed. Further work must be done to attempt to recover adults from experimental hosts.

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Shortfin Mako, *Isurus oxyrinchus*, Impaled by Blue Marlin, *Makaira nigricans* (Teleostei: Istiophoridae)

Harry L. Fierstine,[1] Gregor M. Cailliet,[2] and Julie A. Neer[2]

[1]*Biological Sciences Department, California Polytechnic State University San Luis Obispo, CA 93407*
[2]*Moss Landing Marine Laboratories, Moss Landing, CA 95039-0450*

Although billfish are known to drive their rostra into pelagic sharks, most accounts attribute impalement to the swordfish (*Xiphias gladius*) and not to a member of the family Istiophoridae (Gudger 1940; Smith 1961; Starck 1960). In the only record of a shark having been stabbed by an istiophorid billfish, Cliff et al. (1990) reported that a female shortfin mako (*Isurus oxyrinchus*) was caught off South Africa with the broken rostrum of a sailfish (*Istiophorus platypterus*) embedded in its left orbit. Few other details were given. We present an account of a shortfin mako caught off Baja California, Mexico that was discovered during fish processing operations to have an istiophorid rostrum embedded in its vertebral column (Fig. 1). We briefly discuss the effects of impalement on both shark and billfish.

According to David Arpia (American Sea Food Co., Inc., San Diego, CA, April 3, 1995), "the shark, a male, was caught by longline about 72 km west of Enseñada, Baja California, Mexico, and weighed approximately 28.3 kg dressed. Length was not recorded. It appeared healthy at time of capture with only a slight blemish in its skin where the rostrum entered the body. Except for a capsule of scar tissue surrounding the bone fragment, the flesh appeared normal, and was processed for sale as usual. The broken (posterior) end of the bill fragment was located about two inches (5 cm) below the skin surface." The bill entered the left side of the shark at the level of the second dorsal fin, completely penetrating a vertebral centrum without entering muscle tissue of the right side. A section of the vertebral column with the embedded bill (SIO 94-4) is housed in the Marine Vertebrates Collection, Scripps Institution of Oceanography, La Jolla, CA 92093.

We follow the methodology and terminology of Fierstine and Voigt (1996) and Fierstine and Crimmen (1996) in identifying rostral fragments. Because the bill in this study was a distal segment, measurements and ratios were compared with values from Table 1 of Fierstine and Voigt (1996) at one-fourth bill length (0.25L, or one-fourth the distance between the tip and the orbital margin of the lateral ethmoid).

The bill fragment (Table 1; Fig. 1) is from the distal end of the rostrum and is worn slightly at its tip. We estimate that it was broken slightly anterior to 0.25 L, with paired nutrient canals exposed on the posterior surface. The rostrum is from *Makaira nigricans* (blue marlin) because of the following combination of features: (1) placement of the nutrient canals (DD/D) with respect to depth of the rostrum at 0.25L (=0.65, a value outside the observed range of all istiophorids, but very close to *M. nigricans* and *Tetrapturus angustirostris*); (2) the absence of denticles on the dorsal surface (eliminates all istiophorids inhabiting the Indo-Pacific Ocean except *M. nigricans* and *T. angustirostris*); (3) no evidence of a prenasal in the fragment (eliminates *T. angustirostris*).

Fig. 1. Vertebral segment at level of second dorsal fin of *Isurus oxyrinchus* (SIO 94-4) with embedded rostral fragment of *Makaira nigricans*.

Rostrum morphology suggests the blue marlin was similar in size to Los Angeles County Museum specimen LACM 25491, i.e. slightly less than 44 kg and 173 cm lower jaw to fork length. Blue marlin of this small size would be an immature fish (Hopper 1986).

To obtain an estimate of total length (TL) of the mako shark, we used several morphometric conversion equations developed from second dorsal fin (Garrick 1967; Gubanov 1974; Applegate 1977) and centrum diameter (Cailliet et al. 1983a) measurements in the literature, and from one female shortfin mako with a similar-sized second dorsal fin collected off southern California. Both methods of estimating length resulted in ranges between 200–230 cm TL. We follow the methodology of Cailliet et al. (1983a, b) in estimating age of the shark. Two vertebrae were removed from the vertebral column directly below the second dorsal fin, one immediately anterior and another posterior to insertion of the bill. Age was estimated by counting the number of opaque bands observed in the x-

Table 1. Measurements and ratios of a rostral fragment of *Makaira nigricans* found impaled in *Isurus oxyrinchus* (SIO 94-4).

Measurements (mm)					Ratios		
Length of fragment	Width (W) @ 0.25L	Depth (D) @ 0.25L	Height of nutrient canals (H) @ 0.25L	Distance of nutrient canal from dorsum(DD) @ 0.25L	D/W	H/D	DD/D
98	14.4	9.3	1.0	6.0	0.65	0.11	0.65

rays and by counting ridges along the anterior surface of a whole vertebra. Two different age estimates were produced, one using the assumption of one band pair per year (Cailliet et al. 1983a) and the other using two bands pairs per year (Pratt and Casey 1983a, b).

Both vertebral analysis techniques produced estimates of 7 or 8 band pairs. Thus, the age of this mako was either 3–4 years (Pratt and Casey 1983a, b) or 7–8 years (Cailliet et al. 1983a). A male shortfin mako of this size (200–230 cm TL) would be close to mature (Cailliet et al. 1983a), regardless of age. Female shortfin makos become mature at a larger size, approximately 280 cm TL (Stevens 1983).

There is no evidence to determine if the place of capture of the shortfin mako was also the site of its encounter with the blue marlin. The presence of both *I. oxyrinchus* and *M. nigricans* is more commonly found off Baja California Sur than Baja California. Both species favor a similar epipelagic, oceanic environment, have a worldwide distribution (Compagno 1984; Eschmeyer et al. 1983), and are capable of long distance migrations (Nettles et al. 1994; National Marine Fisheries Service, unpublished).

When the blue marlin broke away from the shark, we assume fracture occurred at the skin surface (the thinnest region of the exposed rostrum) and not within the muscle. Friction between the denticles and the cartilage and muscle tissue probably kept the rostrum from being withdrawn. As both fish struggled to separate, the skin surface functioned as a fulcrum about which the bill fractured in a dorso-ventral plane. Since the rostrum was found 5 cm below the skin surface, the shark grew in caudal diameter (and presumably length) after it had been speared. When compared with vertebrae from an unimpaled shortfin mako of similar size, band patterns did not indicate an alteration of growth after stabbing.

Shortfin makos are opportunistic predators often feeding on scombrids (Compagno 1984) and occasionally on istiophorids, and generally eat prey between 23–35% of their length (Cliff et al. 1990). The sailfish responsible for spearing the mako shark off South Africa (Cliff et al. 1990) was well within the size range of prey consumed by shortfin mako, thus the spearing probably was a defensive response to a predatory act. In contrast, the incident we present here may not have occurred during feeding because the blue marlin probably exceeded the preferred prey size of the shark. We do not know the exact length of either fish at time of impalement but the blue marlin (TL = ~173 cm lower jaw to fork + tip of lower jaw to tip of bill + fork to tip of caudal fin) was probably as long as or longer than the shortfin mako (TL < 200–230 cm).

Most effects of physical encounters between sharks and billfish are unknown. The shortfin mako that was captured off South Africa was impaled in its left orbit and was underweight for its length, and Cliff et al. (1990) speculated that the shark's vision had been impaired enough to affect foraging success. In the case presented here, the shark apparently remained healthy because no vital organ was pierced. In contrast, we know little of the effect on billfish after a rostral fracture. It seems reasonable that loss of a section of the bill would make a billfish more vulnerable to predation, but evidence is lacking. We do know some fish recover from their injuries because there are several records of apparently healthy billfishes with damaged, malformed, or missing rostra (Frazier et al. 1994).

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A Comparative Study of Two Infaunal Sampling Devices: A Modified Van Veen Grab and a Clamshell Box Corer

Douglas R. Diener, Cynthia F. Collins, and Brian D. Riley

MEC Analytical Systems, Inc., 2433 Impala Drive, Carlsbad, California 92008

Abstract.—A new 0.1 m^2 benthic box core sampler, referred to as the CBC (Clamshell Box Corer), has been developed. This sampler can be operated from small vessels and offers substantial improvements over Van Veen samplers, which are commonly used to sample infaunal organisms from southern California coastal areas. Field tests comparing the CBC and a modified, chain-rigged Van Veen showed that the CBC collected larger samples in various sediments tested, required fewer attempts to collect acceptable samples, and generally collected more species of infauna in greater abundance and larger sizes than the Van Veen. Further, because the CBC penetrated more deeply than the Van Veen, it provided a better representation of the infaunal community.

Aquatic studies and monitoring programs require sampling devices that collect consistent and representative samples of the environment. However, for the benthic infaunal sampling component of these programs, these needs have not always been realized because of the variety of sampling devices utilized. Benthic infaunal sampling has been conducted historically using numerous types of grab sampling devices (e.g., Van Veen, box corers, Day, Smith McIntyre, Ponar, Shipek, orange peel) that vary in their design, size, and sampling effectiveness (Gallardo 1965; Tyler and Shackley 1978). Since such variations may affect study results, the comparability of studies using different samplers and the establishment of regional baselines often are limited. Because the emphasis of monitoring programs is shifting towards a regional perspective, the need for uniformity in field sampling protocols and benthic sampling devices becomes even more important. At a minimum, an acceptable benthic sampler should sample a consistent surface area and have sufficient sediment penetration to collect the majority of organisms. Also, the sampler should neither disturb nor distort the surface sediments. Finally, the sampling device should be easy to use and should return the sample to the surface with minimal or no leakage or loss of sediments and organisms.

A 1976 Southern California Coastal Water Research Project (SCCWRP) study compared seven benthic sampling devices (USNEL spade box corer = Reineck box sampler, Van Veen, Ponar, Shipek, No. 1 Orange Peel, modified Van Veen, and Smith McIntyre) for six criteria of physical performance (penetration depth, surface area, sediment disturbance, leakage, sample volume, and sampling reliability) (Word et al. 1976). This study concluded that the overall best sampling device was the box corer. However, because of the size and weight of the box core sampler, its usefulness was limited to larger research vessels. For general usage, a Van Veen grab sampler modified to reduce a significant "bow wave" effect (as noted by Wigley 1967) was recommended. The results of the SCCWRP study led to the use of a modified Van Veen grab sampler for many monitoring

studies in southern California. Unfortunately, even the modified Van Veen sampler is not a perfect device. The surface area sampled is dependent upon the extent to which the jaws are opened, and the sampler requires proper rigging before each deployment. Furthermore, penetration in sandy sediments is poor, and significant surface distortion occurs as the jaws close. Because of these limitations of the modified Van Veen, there has been a continuing effort to develop a sampling device that retains the better qualities of a box corer yet still is small enough for general usage. This study compares the infaunal sampling ability of a small clamshell box corer (CBC) with a modified Van Veen grab sampler.

Methods

Performances of the CBC and a chain-rigged, modified, 0.1 m^2 Van Veen sampler were compared by taking grab samples at five different station locations along the 60m contour off Huntington Beach, California. These locations are part of the regular sampling grid for the treated wastewater outfall monitoring program conducted by the County Sanitation Districts of Orange County (CSDOC). The stations were selected because of the range of sediment characteristics and locations relative to the wastewater discharge. Station 1 is located about 0.5 km upcoast from the diffuser and is characterized by sediments of mixed green sand (73%) and mud (27%). Station 37 is located on the edge of Newport Canyon, approximately 3.4 km downcoast from the diffuser and is typified by sandy sediments (90%) with significant amounts of relic shell hash, bivalve shells, and calcareous worm tubes. Stations Control and C are located 7.8 and 5.6 km, respectively, upcoast from the diffuser and have mixed sand (79%) and green mud (21%). Station C also contains significant shell hash. Station C2 is located in Newport Canyon, approximately 6.2 km downcoast from the diffuser, and has green, brown, and black, fine mud (96%) with relatively few infauna.

The CBC, designed and built by D. Diener, has overall dimensions of approximately 50.8 cm by 40.6 cm (Fig. 1). The inside of the sampling box is 33.0 cm by 30.3 cm to provide a 0.1 m^2 sample surface area. The inside height is 35.0 cm. The weight of the CBC is about 27 kg, with the working weight adjustable from 27 to 175 kg. In fine sediments the sampler is used without weights, but weights are added for sand to achieve sufficient sediment penetration. In the present study, 75 kg of weights were added for sandy sediments, and 110 kg of weights were added at Stations 37 and C, due to the shell hash in their sediments. No weight was added at Station C2, which is composed primarily of silt.

Five replicate samples were collected at Stations 1, 37, and Control in July 1992 using the Van Veen grab sampler and the CBC. Stations C and C2 were sampled in a similar manner in July 1993. Sample acceptance criteria included (1) a minimal volume of 4 liters (thereby representing sufficient sampler penetration and retrieval of the majority of organisms) and (2) a relatively undisturbed surface for the Van Veen and an undisturbed surface for the CBC. Total sample volume was measured in the field using a bucket calibrated in liters. All samples were sieved through a 1.0 mm screen, and retained sediments and organisms were fixed in 10% formalin in the field and returned to the laboratory for processing. Samples were sorted to major taxonomic groups and identified and enumerated by species. Wet weight biomass of major taxonomic groups was determined after the taxonomic analysis.

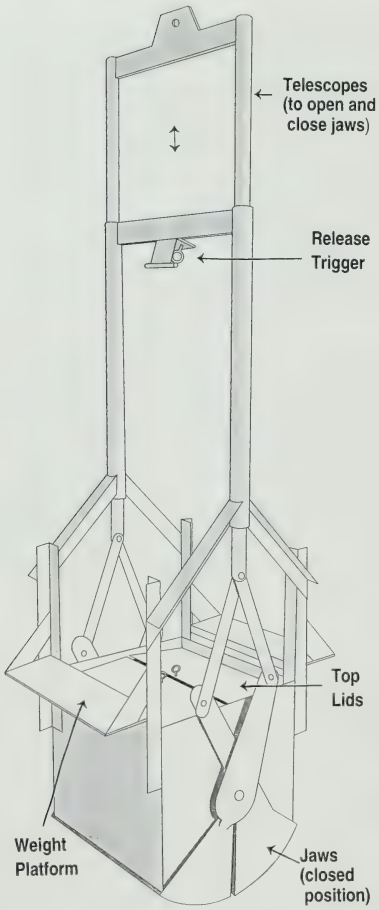

Fig. 1. Clamshell box core sampler.

Results and Discussion

Sampler Efficiency and Sediment Penetration

The number of drops needed to collect five replicate samples is shown in Table 1. The Van Veen sampler and the CBC required a similar number of drops to collect five good samples at all stations except Station 37. The Van Veen required more than five drops to collect five good samples because of insufficient sample volume, pretripping of the sampler due to boat motion caused by swells, and

Table 1. Number of attempts needed to collect five acceptable samples by the two samplers.

Station	Van Veen	CBC
1	7	6
37	18	8
Control	7	5
C	5	6
C2	5	7

Table 2. Total sample volume (liters).

	Station	CBC	Van Veen
Mean	1	9.3	4.8
Range		8.0–10.75	4.5–5.25
Mean	37	8.7	4.6
Range		7.75–9.5	4.0–5.5
Mean	Control	10.6	5.6
Range		9.75–12.25	4.75–7.0
Mean	C	10.15	6.35
Range		9.25–11.25	5.5–7.25
Mean	C2	24.6	18
Range		23–25	18

prevention of sampler closure due to chain problems or shell hash and/or calcareous worm tubes caught in the jaws. The CBC required more than five drops because shell hash or worm tubes prevented closure of the jaws, and at Stations C and C2 in 1993 the release mechanism did not function properly on two drops. Continued modifications in the design have improved the functioning of the CBC release mechanism. At Station 37 the CBC required fewer than half the number of drops of the Van Veen. This suggests that the box corer is a more reliable sampling device, which could reduce sampling time and costs for field studies.

Another important comparison for sampling devices is the volume of sediment, which is proportional to sediment penetration. The CBC collected substantially greater sample volumes than the Van Veen at all five stations and approximately twice the sample volume of the Van Veen for Stations 1, 37, and Control (Table 2). The smallest volumes were collected at Station 37, which had the sandiest sediments, and the largest volumes were collected at Station C2, where sediments were composed primarily of fine silt and at which sampler penetration was greatest. However, sample volumes at Station Control were larger than those collected at Station 1 even though the Station Control sediments were not as fine as those from Station 1. This difference may be due to comparatively high abundances of ophiuroids at Station Control. Ophiuroids are thought to rework the sediments and make them less compacted, thereby potentially allowing for deeper sampler penetration. The significance of sampler penetration is that, while the majority of infaunal organisms are in the upper few centimeters, some organisms (e.g., *Amphiodia, Solen, Ensis, Neotrypaea*) are found more deeply or they may burrow more deeply as they grow larger. These differences may affect species richness, abundance, and biomass estimates.

Infauna

Infaunal abundance, number of species, and biomass are the parameters most widely used in monitoring studies for description of the infaunal community and assessment of environmental impacts. Table 3 provides a comparison between the two samplers for these community parameters. The CBC, on average, collected more organisms than the Van Veen sampler at all five stations, although the difference between the two was negligible at Station C. The CBC collected almost 60% more organisms than the Van Veen at Station C2 and approximately 25%

Table 3. Comparison of infaunal abundance, number of species, and wet weight biomass (grams) for the two samplers.

	Infaunal abundance		Number of species		Infaunal biomass	
	CBC	Van Veen	CBC	Van Veen	CBC	Van Veen
			Station 1			
Mean	828*	663*	121*	110*	6.07	4.27
Range	688–890	605–713	113–128	102–119	3.54–12.0	1.89–8.39
			Station 37			
Mean	440	386	110	101	9.20*	2.91*
Range	242–623	322–482	78–137	82–125	6.70–12.3	1.55–4.74
			Station Control			
Mean	415	396	96.8	104	9.70	7.30
Range	358–438	328–559	85–103	93–123	6.84–14.2	5.16–10.1
			Station C			
Mean	553	552	118*	98.4*	9.06*	6.77*
Range	451–691	450–624	106–128	79–111	7.38–10.6	5.84–7.41
			Station C2			
Mean	126*	79*	40.6*	32.4*	3.61*	2.15*
Range	83–172	65–93	31–49	29–35	2.76–4.20	1.62–2.66

* Statistically significant t test $P \leq 0.05$.

more organisms at Station 1. For both stations, the difference was statistically significant (t test; $p \leq 0.05$, Table 3). For Stations 37 and Control, the CBC collected 14.5% and 4.8% more individuals, respectively; however, these differences were not statistically significant.

The CBC also sampled a greater number of species than the Van Veen at four of the five stations (Table 3). In three of these cases, the results were statistically significant with the CBC collecting 25.3% more species at Station C2, 19.7% more species at Station C, and 10.6% more species at Station 1. The CBC collected 8.7% more species at Station 37 and 6.7% fewer species at Station Control than the Van Veen; these comparisons were not statistically significant. Biomass measurements were higher at all stations for the CBC and were significantly greater for Stations 37, C, and C2. Biomass was higher by 42.2% at Station 1, 216% at Station 37, 32.9% at Station Control, 33.8% at Station C, and 67.9% at Station C2. The higher infaunal biomass collected with the CBC appears to be related to the deeper penetration of the CBC and the collection of larger, deep-burrowing organisms.

An analysis of the data by major taxonomic groups further defines differences between the two sampling devices (Table 4). More polychaete species were collected with the CBC at Stations 1 (15.1%), 37 (10.6%), C (25.9%), and C2 (29.9%), but fewer species were collected at Station Control (−4.4%). The higher numbers of species at Stations 1 and C were statistically significant. More polychaete individuals were collected with the CBC at Stations 1 (35.6%), 37 (9.5%), C (3.3%), and C2 (84.6%) and slightly fewer at Station Control (−1.2%). The higher polychaete abundance for Station 1 was statistically significant.

There were no significant differences for crustacean abundance and number of species between the two samplers. On average, the CBC collected more crustacean

Table 4. Comparison of average number of species and abundance for the major taxonomic groups.

	Station 1		Station 37		Station Control		Station C		Station C2	
	CBC	Van Veen	CBC	Van Veen	CBC	Van Veen	CBC	Van Veen	CBC	Van Veen
Polychaete species	53.4*	46.4*	56.2	50.8	47.8	50.0	62.2*	49.4*	22.6	17.4
Polychaete abundance	477*	352*	214	195	219	222	344	333	72	39
Crustacean species	33.4	30.0	20.6	18.8	29.0	31.6	31.2	28.2	4.2	3.0
Crustacean abundance	209	192	55	58	102	100	85	86	14	9
Mollusc species	17.4	17.2	12.6	13.4	6.6*	9.0*	8.8	9.6	10.0	8.2
Mollusc abundance	71	66	35	33	11	13	25	31	28	20
Echinoderm species	4.6	4.6	4.4	4.0	4.6	4.2	6.0	4.0	1.0	1.8
Echinoderm abundance	19	14	24*	10*	62*	41*	84	89	7	8
Minor phyla species	12.6	11.6	16.2	14.2	8.8	9.0	9.6	7.2	2.8	2.0
Minor phyla abundance	53*	40*	112	89	21	21	14	13	4	3

* Statistically significant t test $P \leq 0.05$.

species at Stations 1 (11.3%), 37 (9.6%), C (10.6%), and C2 (40%) and fewer at Station Control (−8.2%). More crustacean individuals were collected with the CBC at Stations 1 (8.9%), Control (2.6%), and C2 (55.6%), but fewer at Stations 37 (−5.5%) and C (−1.2%).

The CBC collected more molluscan species at Stations 1 (1.2%) and C2 (22.0%) and fewer species at Stations 37 (−6.0%), Control (−26.7%), and C (−9.1%). The difference for Station Control was statistically significant and was one of only two instances where the Van Veen sampler statistically exceeded the CBC for the collection of organisms. The CBC collected more molluscan individuals at Stations 1 (8.5%), 37 (4.2%), and C2 (40.0%) and fewer at Stations Control (−17.9%) and C (−24.0%). There is no obvious explanation as to why the CBC collected fewer molluscs at Stations Control and C, although these two stations are similar in sediment type.

An important finding was that the CBC sampled the echinoderm population more effectively than did the Van Veen at most of the stations. The number of species collected with the CBC equaled or exceeded those of the Van Veen for four of the five stations. The CBC collected a greater number of species at Stations 37 (10.0%), Control (9.5%), and C (50%) and sampled an equal or comparable number at Stations 1 and C2, respectively. Echinoderm abundance was greater at three of the stations in samples collected by the CBC. This is related to the greater penetration depths of the CBC since ophiuroids, which are the dominant echinoderm found in the CSDOC monitoring program, tend to be buried in the sediments. At Station C2, which is composed of fine, soft silt, the Van Veen was able to penetrate deeply enough to collect a comparable number of echinoderm individuals as the CBC. In sandier sediments, the CBC was generally more effective. The CBC collected 35.7% more echinoderm individuals at Station 1, significantly more (129%) at Station 37, and significantly more (51.7%) at Station Control. It collected slightly fewer individuals at Stations C and C2. Therefore, it appears that the Van Veen is underestimating the number of ophiuroids due to shallower sampler penetration into sandy sediments. These overall results are significant because of the importance attributed to ophiuroids as sensitive indicators of impacts associated with wastewater discharges.

The CBC collected more minor phyla species at Stations 1 (8.6%), 37 (14.1%), C (33%), and C2 (40%) and slightly fewer species at Station Control (−2.2%); however, these differences were not significant. Compared to the Van Veen, the CBC also collected more minor phyla individuals at Stations 1 (32.8%), 37 (26.9%), C (8.0%), and C2 (33%), but a similar number of individuals at Station Control. The higher abundance at Station 1 was significant.

Disturbance of Surface

Both devices were able to collect samples with minimal leakage, except at Station C2 where sediment leakage through the top of the Van Veen sampler was common. At all stations except Station C2, the Van Veen caused the sediments in the middle of the sampler to be "humped," indicating some surface disturbance of the collected sample. This humping was not observed with the CBC because the amount of weight can be adjusted so that it is proportional to the depth of penetration (the weights are easily removed). The sampler's weight platform also provides a large surface near the top of the CBC that further limits the depth of

sampler penetration (see Fig. 1). In contrast, the Van Veen sampler uses four contoured weights that change the penetration profile, and removing these weights generally is not practical. The depth of penetration for the Van Veen is, therefore, highly dependent on the sediment type.

Conclusion

A 1976 SCCWRP study concluded that the best device for sampling infaunal organisms was the box corer. The present study, which compared a small clam-shell box corer with a modified Van Veen grab sampler, confirms this earlier research. Overall results indicate that the CBC samples the infaunal community more efficiently and with less surface distortion than does the Van Veen grab. The CBC is easy to use and collects good samples more often than the Van Veen. In addition, the CBC provides a better representation of the infaunal community by collecting infauna that live more deeply in the sediments.

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The BULLETIN is published three times each year (April, August, and December) and includes articles in English in any field of science with **an emphasis on the southern California area**. Manuscripts submitted for publication should contain results of original research, embrace sound principles of scientific investigation, and present data in a clear and concise manner. The current AIBS *Style Manual for Biological Journals* is recommended as a guide for contributors. Consult also recent issues of the BULLETIN.

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All manuscripts should be submitted to the Editor, Daniel A. Guthrie, W. M. Keck Science Center, 925 North Mills Avenue, Claremont, CA 91711. **Authors are requested to submit the names, addresses and specialities of three persons who are capable of reviewing the manuscript. Evaluation of a paper** submitted to the BULLETIN begins with a critical reading by the Editor; several referees also check the paper for scientific content, originality, and clarity of presentation. Judgments as to the acceptability of the paper and suggestions for enhancing it are sent to the author at which time he or she may be requested to rework portions of the paper considering these recommendations. The paper then is resubmitted and may be re-evaluated before final acceptance.

Proof: The galley proof and manuscript, as well as reprint order blanks, will be sent to the author. He or she should **promptly** and **carefully read** the proof sheets for errors and omissions in text, tables, illustrations, legends, and bibliographical references. He or she marks corrections on the galley (copy editing and proof procedures in *Style Manual*) and **promptly returns both galley and manuscript** to the Editor. Manuscripts and original illustrations will not be returned unless requested at this time. **All changes in galley proof attributable to the author (misspellings, inconsistent abbreviations, deviations from style, etc.) will be charged to the author. Reprint orders are placed with the printer, not the *Editor.***

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COVER: *Phrixocephalus cincinnatus,* female. Copepod eye parasite from Pacific sanddab. Photograph by Bob Wagoner and Penny S. Perkins, Department of Veterans Affairs, Medical Center, La Jolla, CA.